



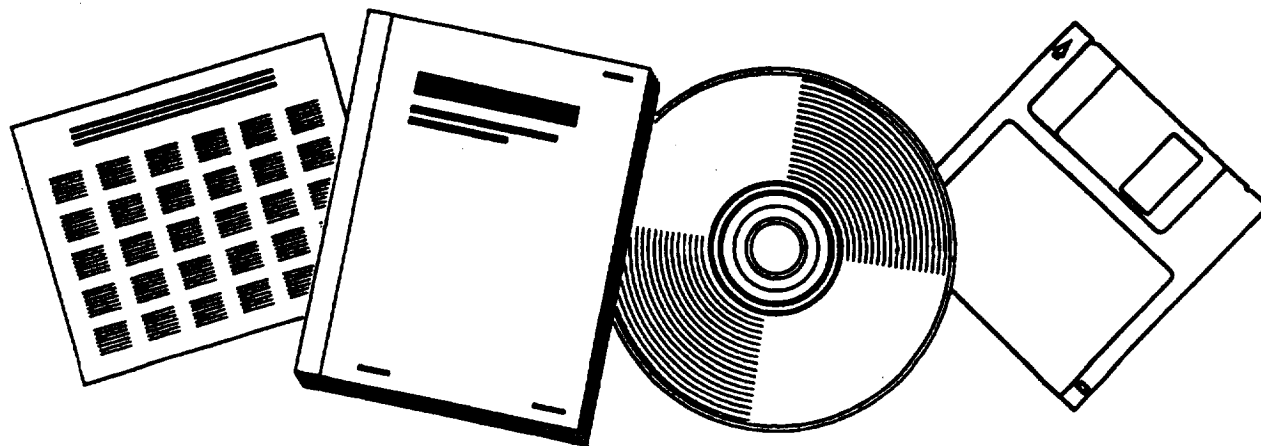
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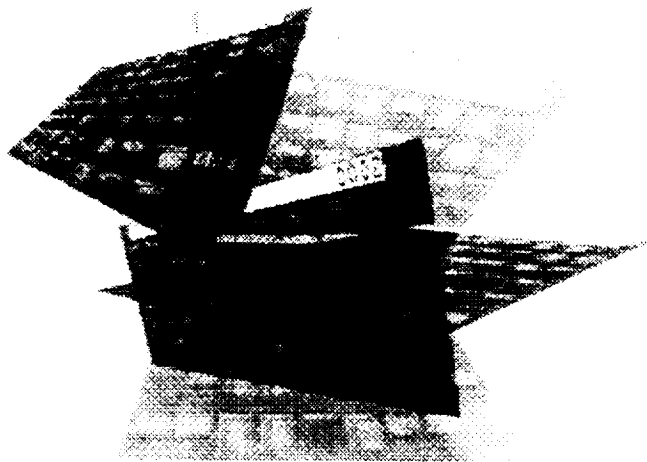
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A Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics Part III: Program Manual

Wayne Johnson

June 1980

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A Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics Part III: Program Manual

Wayne Johnson, Aeromechanics Laboratory
AVRADCOM Research and Technology Laboratories
Ames Research Center, Moffett Field, California



National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

United States Army
Aviation Research and
Development Command
St. Louis, Missouri 63166



CONTENTS

page
1

1. Common Block Contents

| | |
|--------|----|
| TMDATA | 2 |
| R1DATA | 4 |
| W1DATA | 7 |
| G1DATA | 8 |
| BDDATA | 9 |
| BADATA | 11 |
| ENDATA | 12 |
| L1DATA | 13 |
| LADATA | 14 |
| GCDATA | 15 |
| TNDATA | 16 |
| STDATA | 17 |
| FLDATA | 18 |
| A1TABL | 20 |
| CASECM | 21 |
| UNITNO | 22 |
| TRIMCM | 23 |
| RTR1CM | 24 |
| RH1CM | 26 |
| BCDYCM | 27 |
| ENGNCM | 29 |
| GUSTCM | 30 |
| CONTCM | 31 |
| CONVCM | 32 |
| MD1CM | 33 |
| INC1CM | 35 |
| WKV1CM | 37 |
| MNH1CM | 38 |
| AES1CM | 39 |
| MNR1CM | 40 |
| MNSCM | 41 |
| AEF1CM | 42 |
| QR1CM | 43 |
| QBDCM | 44 |
| WG1CM | 45 |
| WKC1CM | 46 |
| AEMNCM | 47 |
| LDMNCM | 48 |
| FLMCM | 49 |
| FLM1CM | 50 |
| FLMACM | 51 |
| FLINCM | 52 |
| FLAECM | 53 |
| STDCM | 55 |
| STMCM | 56 |
| TRANCM | 57 |

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TYPE TRANS ☒

NO TAB ☐

DESCRIPTION ☐

By _____

DESCRIPTION/ _____

Accession Number _____

DATE _____

FILE _____

A

2. Subprogram Function and Communication

page
58

| | |
|--------|-----|
| MAIN | 59 |
| TIMER | 60 |
| INPTN | 61 |
| INPTO | 62 |
| INPTA1 | 63 |
| INPTR1 | 64 |
| INPTW1 | 65 |
| INPTB | 66 |
| INPTL1 | 67 |
| INPTF | 68 |
| INPTS | 69 |
| INPTT | 70 |
| INPTG | 71 |
| INPTU | 72 |
| INPTV | 73 |
| FILEI | 74 |
| FILEJ | 75 |
| FILER | 76 |
| FILEF | 77 |
| FILES | 78 |
| FILET | 79 |
| FILEE | 80 |
| INIT | 81 |
| INITA | 82 |
| INITC | 83 |
| INITR1 | 85 |
| INITB | 88 |
| INITE | 90 |
| CHEKR1 | 91 |
| PRNTJ | 92 |
| PRNTC | 93 |
| PRNT | 95 |
| PRNTR1 | 96 |
| PRNTW1 | 97 |
| PRNTB | 98 |
| PRNTF | 99 |
| PRNTS | 100 |
| PRNTT | 101 |
| PRNTG | 102 |
| TRIM | 103 |
| TRIMI | 104 |
| TRIMP | 107 |
| FLUT | 109 |
| FLUTM | 110 |
| FLUTB | 114 |
| FLUTR1 | 115 |
| FLUTI1 | 117 |
| FLUTA1 | 118 |
| FLUTL | 120 |

| | page |
|--------|------|
| STAB | 121 |
| STABM | 122 |
| STABD | 124 |
| STABE | 125 |
| STABL | 126 |
| STABP | 127 |
| TRAN | 129 |
| TRANI | 131 |
| TRANP | 133 |
| TRANC | 135 |
| CONTRL | 136 |
| GUSTU | 137 |
| GUSTC | 138 |
| PERF | 139 |
| PERFR1 | 142 |
| LOAD | 144 |
| LOADR1 | 145 |
| LOADH1 | 148 |
| LOADS1 | 150 |
| LOADI1 | 152 |
| LOADF | 154 |
| LOADM | 155 |
| GEOMP1 | 156 |
| POLRPP | 158 |
| HISTPP | 159 |
| NOISR1 | 161 |
| BESSEL | 163 |
| BAMF | 164 |
| MODE1 | 166 |
| MODEC1 | 167 |
| MODEB1 | 169 |
| MODEG | 171 |
| MODEA1 | 172 |
| MODET1 | 173 |
| MODEK1 | 174 |
| MODED1 | 175 |
| INRTC1 | 176 |
| MODEP1 | 178 |
| BODYC | 180 |
| ENGNC | 182 |
| MOTNC1 | 184 |
| BODYM1 | 186 |
| ENGNM1 | 187 |
| WAKEU1 | 188 |
| WAKEN1 | 190 |
| INRTM1 | 192 |
| INRTI | 194 |
| MOTNH1 | 195 |
| MCTNR1 | 196 |
| MOTNB1 | 198 |

| | page |
|--------------------------------|------|
| AEROF1 | 199 |
| AEROS1 | 202 |
| AEROT1 | 204 |
| BCDYV1 | 205 |
| ENGNV1 | 206 |
| MOTNF1 | 207 |
| MCTNS | 208 |
| BODYF | 209 |
| BODYA | 211 |
| WAKEC1 | 212 |
| WAKEB1 | 215 |
| VTXL | 216 |
| VTXS | 217 |
| GECME1 | 218 |
| GEOMR1 | 219 |
| GEOMF1 | 220 |
| MINV | 221 |
| MINVC | 222 |
| EIGENJ | 223 |
| DERED | 224 |
| QSTRAN | 225 |
| CSYSAN | 226 |
| DETRAN | 228 |
| SINE | 229 |
| STATIC | 230 |
| ZERO | 231 |
| ZETRAN | 232 |
| BODE | 233 |
| BODEPP | 234 |
| TRACKS | 235 |
| TRCKPP | 237 |
| GUSTS | 238 |
| PSYSAN | 240 |
| DEPRAN | 242 |
| MAINTB | 243 |
| AEROT | 244 |
| AEROPP | 245 |
| 3. Computer System Subprograms | 246 |
| 4. Core Requirements | 247 |

A COMPREHENSIVE ANALYTICAL MODEL OF
ROTORCRAFT AERODYNAMICS AND DYNAMICS

Part III: Program Manual

Wayne Johnson

Ames Research Center
and
Aeromechanics Laboratory
AVRADCOM Research and Technology Laboratories

SUMMARY

The computer program for a comprehensive analytical model of rotorcraft aerodynamics and dynamics is described. This analysis is designed to calculate rotor performance, loads, and noise; the helicopter vibration and gust response; the flight dynamics and handling qualities; and the system aeroelastic stability. The analysis is a combination of structural, inertial, and aerodynamic models, that is applicable to a wide range of problems and a wide class of vehicles. The analysis is intended for use in the design, testing, and evaluation of rotors and rotorcraft, and to be a basis for further development of rotary wing theories. This report documents the computer program that implements the analysis.

1. COMMON BLOCK CONTENTS

This section describes the contents of the common blocks used by the program. Each description begins with the common block label. The total length of the block is given in parentheses after the label. Then all variables in the block are listed. The left-hand column gives the variable name, and the right-hand column gives the location of the variable in the common block. Finally, a description of the variable is provided (except for variables in blocks with labels of the form xxDATA, which are input parameters). Only the common blocks for rotor #1 are described; the common blocks for rotor #2 have an identical structure.

TMDATA(182)

| | | |
|------------|--|-----|
| FILEID(4) | input file identification (alphanumeric date and time; BLOCK DATA if input file is neither read nor written) | 1 |
| TITLE(20) | | 5 |
| CODE | | 25 |
| ANTYPE(3) | | 26 |
| OPREAD(10) | | 29 |
| NPRNTI | | 39 |
| DEBUG(25) | | 40 |
| OPUNIT | | 65 |
| NROTOR | | 66 |
| ALTMSL | | 67 |
| TEMP | | 68 |
| VKTS | | 69 |
| VEL | | 70 |
| VTIP | | 71 |
| RPM | | 72 |
| OPGRND | | 73 |
| HAGL | | 74 |
| OPENGW | | 75 |
| AFLAP | | 76 |
| MPSI | | 77 |
| DENSE | | 78 |
| OPDENS | | 79 |
| COLL | | 80 |
| LATCYC | | 81 |
| LNGCYC | | 82 |
| PEDAL | | 83 |
| APITCH | | 84 |
| AROLL | | 85 |
| ACLIMB | | 86 |
| AYAW | | 87 |
| RTURN | | 88 |
| MPSIR | | 89 |
| MREV | | 90 |
| ITERM | | 91 |
| EPMOTN | | 92 |
| ITERC | | 93 |
| EPCIRC | | 94 |
| DOF(54) | | 95 |
| DOFT(8) | | 149 |
| LEVEL(2) | | 157 |
| ITERU | | 159 |
| ITERR | | 160 |
| ITERF | | 161 |
| NPRNTT | | 162 |
| NPRNTP | | 163 |
| NPRNTL | | 164 |

| | TMDATA |
|-----------|--------|
| CXTRIM | 165 |
| XTRIM | 166 |
| CTTRIM | 167 |
| CPTRIM | 168 |
| CYTRIM | 169 |
| BCTRIM | 170 |
| BSTRIM | 171 |
| MTRIM | 172 |
| MTRIMD | 173 |
| DELTA | 174 |
| FACTOR | 175 |
| EPTRIM | 176 |
| OPGOVT | 177 |
| OPTRIM | 178 |
| MHARM(2) | 179 |
| MHARME(2) | 181 |

R1DATA(932)

| | |
|-----------|----|
| TITLE(20) | 1 |
| TYPE | 21 |
| VTIPN | 22 |
| RADIUS | 23 |
| SIGMA | 24 |
| GAMMA | 25 |
| NBLADE | 26 |
| TDAMPO | 27 |
| TDAMPC | 28 |
| TDAMPR | 29 |
| NUGC | 30 |
| NUGS | 31 |
| GDAMPC | 32 |
| GDAMPS | 33 |
| LDAMPC | 34 |
| LDAMPM | 35 |
| LDAMPR | 36 |
| BTIP | 37 |
| OPTIP | 38 |
| LINTW | 39 |
| TWISTL | 40 |
| ROTATE | 41 |
| OPHVIB(3) | 42 |
| CPUSLD | 45 |
| GSB(10) | 46 |
| GST(5) | 56 |
| TAU(3) | 61 |
| ADELAY | 64 |
| AMAXNS | 65 |
| PSIDS(3) | 66 |
| ALFDS(3) | 69 |
| ALFRE(3) | 72 |
| CLDSP | 75 |
| CDDSP | 76 |
| CMDSP | 77 |
| OPYAW | 78 |
| OPSTLL | 79 |
| OPCOMP | 80 |
| RROCT | 81 |
| KHLMDA | 82 |
| KFLMDA | 83 |
| FXLMDA | 84 |
| FYLMDA | 85 |
| FMLMDA | 86 |
| FACTWU | 87 |
| KINTH | 88 |
| KINTF | 89 |
| KINTWB | 90 |
| KINTHT | 91 |

| | R1 DATA |
|------------|---------|
| KINTVT | 92 |
| INFLOW(6) | 93 |
| RGMAX | 99 |
| NOPB | 100 |
| RCPL | 101 |
| KFLAP | 102 |
| KLAG | 103 |
| RCPLS | 104 |
| TSPRNG | 105 |
| NCOLB | 106 |
| NONROT | 107 |
| HINGE | 108 |
| NCOLT | 109 |
| KPIN | 110 |
| PHIPH | 111 |
| PHIPL | 112 |
| RPB | 113 |
| RPH | 114 |
| XPH | 115 |
| ATANKP(10) | 116 |
| DEL3G | 126 |
| MBLADE | 127 |
| EPMODE | 128 |
| MRB | 129 |
| MRM | 130 |
| MASST | 131 |
| XIT | 132 |
| EFLAP | 133 |
| ELAG | 134 |
| RFA | 135 |
| ZFA | 136 |
| XFA | 137 |
| WTIN | 138 |
| FTO | 139 |
| FTC | 140 |
| FTR | 141 |
| KTO | 142 |
| KTC | 143 |
| KTR | 144 |
| CONE | 145 |
| DROOP | 146 |
| SWEEP | 147 |
| FDROOP | 148 |
| FSWEEP | 149 |
| MRA | 150 |
| RAE(31) | 151 |
| CHORD(30) | 182 |
| XAC(30) | 212 |
| XA(30) | 242 |

TWISTA(30)
 THETZL(30)
 MCORRL(30)
 MCORRD(30)
 MCORRM(30)
 MRI
 RI(51)
 XI(51)
 XC(51)
 KP2(51)
 MASS(51)
 ITHETA(51)
 GJ(51)
 EIXX(51)
 EIZZ(51)
 TWISTI(51)

R1DATA

272
 302
 332
 362
 392
 422
 423
 474
 525
 576
 627
 678
 729
 780
 831
 882

W1DATA(126)

| | |
|------------|-----|
| FACTNW | 1 |
| OPVXVY | 2 |
| KNW | 3 |
| KRW | 4 |
| KFW | 5 |
| KDW | 6 |
| RRU | 7 |
| FRU | 8 |
| PRU | 9 |
| FNW | 10 |
| DVS | 11 |
| DLS | 12 |
| CORE(5) | 13 |
| OPCORE(2) | 18 |
| WKMODL(13) | 20 |
| OPNWS(2) | 33 |
| LHW | 35 |
| OPHW | 36 |
| OPRTS | 37 |
| VELB | 38 |
| DPHIB | 39 |
| DBV | 40 |
| QDEBUG | 41 |
| MRC | 42 |
| NG(30) | 43 |
| MRL | 73 |
| NL(30) | 74 |
| OPWKBP(3) | 104 |
| KRWG | 107 |
| OPRWG | 108 |
| FWGT(2) | 109 |
| FWGSI(2) | 111 |
| FWGSO(2) | 113 |
| KWGT(4) | 115 |
| KWGSI(4) | 119 |
| KWGSO(4) | 123 |

G1DATA(55)

| | |
|-----------|----|
| KFWG | 1 |
| OPFWG | 2 |
| ITERWG | 3 |
| FACTWG | 4 |
| WGMDL(2) | 5 |
| RTWG(2) | 7 |
| COREWG(4) | 9 |
| MRVBWG | 13 |
| LDMWG | 14 |
| NDMWG(36) | 15 |
| IPWGDB(2) | 51 |
| QWGDB | 53 |
| DQWG(2) | 54 |

BDDATA(345)

| | |
|-----------|----|
| TITLE(20) | 2 |
| WEIGHT | 21 |
| IXX | 22 |
| IYY | 23 |
| IZZ | 24 |
| IXY | 25 |
| IXZ | 26 |
| IYZ | 27 |
| TRATIO | 28 |
| CONFIG | 29 |
| ASHAFT(2) | 30 |
| ACANT(2) | 32 |
| ATILT | 34 |
| FSR1 | 35 |
| BLR1 | 36 |
| WLR1 | 37 |
| FSR2 | 38 |
| BLR2 | 39 |
| WLR2 | 40 |
| FSWB | 41 |
| BLWB | 42 |
| WLWB | 43 |
| FSHT | 44 |
| BLHT | 45 |
| WLHT | 46 |
| FSVT | 47 |
| BLVT | 48 |
| WLVT | 49 |
| FSOFF | 50 |
| BLOFF | 51 |
| WLOFF | 52 |
| FSCG | 53 |
| BLCG | 54 |
| WLCG | 55 |
| HMAST | 56 |
| DPSI21 | 57 |
| CANTHT | 58 |
| CANTVT | 59 |
| KOCFE | 60 |
| KCCFE | 61 |
| KSCFE | 62 |
| KPCFE | 63 |
| PCCFE | 64 |
| PSCFE | 65 |
| PPCFE | 66 |
| KFOCFE | 67 |
| KROCFE | 68 |
| KFCCFE | 69 |

| | BDDATA |
|--------------|--------|
| KRCCFE | 70 |
| KFSCFE | 71 |
| KRSCFE | 72 |
| KFPCFE | 73 |
| KRPCFE | 74 |
| PFCCFE | 75 |
| PRCCFE | 76 |
| PFPCFE | 77 |
| PRPCFE | 78 |
| KFCFE | 79 |
| KTCFE | 80 |
| KACFE | 81 |
| KECFE | 82 |
| KRCFE | 83 |
| CNTRLZ(11) | 84 |
| NEM | 95 |
| KPMC1(10) | 96 |
| KPMS1(10) | 106 |
| KPMC2(10) | 116 |
| KPMS2(10) | 126 |
| ZETAR1(3,10) | 136 |
| GAMAR1(3,10) | 166 |
| ZETAR2(3,10) | 196 |
| GAMAR2(3,10) | 226 |
| QMASS(10) | 256 |
| QFREQ(10) | 266 |
| QDAMP(10) | 276 |
| QDAMPA(10) | 286 |
| QCNTL(4,10) | 296 |
| DOFSYM(10) | 336 |

BADATA(37)

| | |
|--------|----|
| LFTAW | 1 |
| IWB | 2 |
| LFTDW | 3 |
| LFTFW | 4 |
| DRGOW | 5 |
| DRGVW | 6 |
| DRGIW | 7 |
| DRGDW | 8 |
| DRGFW | 9 |
| AMAXW | 10 |
| MOMOW | 11 |
| MOMAW | 12 |
| MOMDW | 13 |
| MOMFW | 14 |
| SIDEB | 15 |
| SIDEP | 16 |
| SIDER | 17 |
| ROLLB | 18 |
| ROLLP | 19 |
| ROLLR | 20 |
| ROLLA | 21 |
| YAWB | 22 |
| YAWP | 23 |
| YAWR | 24 |
| YAWA | 25 |
| LFTAH | 26 |
| LFTEH | 27 |
| AMAXH | 28 |
| IHT | 29 |
| LFTAV | 30 |
| LFTRV | 31 |
| AMAXV | 32 |
| IVT | 33 |
| FETAIL | 34 |
| LHTAIL | 35 |
| HVTAIL | 36 |
| OPTINT | 37 |

ENDATA(22)

| | |
|--------|----|
| ENGPOS | 1 |
| THRTL | 2 |
| IENG | 3 |
| KMAST1 | 4 |
| KMAST2 | 5 |
| KICS | 6 |
| KENG | 7 |
| KPGOVE | 8 |
| KPGOV1 | 9 |
| KPGOV2 | 10 |
| KIGOVE | 11 |
| KIGOV1 | 12 |
| KIGOV2 | 13 |
| T1GOVE | 14 |
| T1GOV1 | 15 |
| T1GOV2 | 16 |
| T2GOVE | 17 |
| T2GOV1 | 18 |
| T2GOV2 | 19 |
| GSE | 20 |
| GSI | 21 |
| KEDAMP | 22 |

L1DATA(239)

| | |
|------------|-----|
| MHARML | 1 |
| MHLOAD | 2 |
| MALOAD | 3 |
| MRLOAD | 4 |
| RLOAD(20) | 5 |
| NPOLAR | 25 |
| NWKGMP(4) | 26 |
| MWKGMP | 30 |
| JWKGMP(8) | 31 |
| MHARMN(3) | 39 |
| MTIMEN(3) | 42 |
| MNOISE | 45 |
| RANGE(10) | 46 |
| ELVATN(10) | 56 |
| AZMUTH(10) | 66 |
| KFATIG | 76 |
| SENDUR(18) | 77 |
| CMAT(18) | 95 |
| EXMAT(18) | 113 |
| NPLOT(75) | 131 |
| AXS(30) | 206 |
| OPNOIS(4) | 236 |

LADATA(331)

MVIB

1

FSVIB(10)

2

WLVIB(10)

12

BLVIB(10)

22

ZETAV(3,10,10)

32

GCDATA(18)

OPTRAN
OPGUST(3)
VELG
PSIG
GDIST(2)
GTIME
CTIME
GMAG(3)
CMAG(5)

1
2
5
6
7
9
10
11
14

TNDATA(42)

| | |
|------------|----|
| NPRNTT | 1 |
| NPRNTP | 2 |
| NPRNTL | 3 |
| NRSTRT | 4 |
| TMAX | 5 |
| TSTEP | 6 |
| OPPLOT | 7 |
| DOFPLT(21) | 8 |
| DOF(7) | 29 |
| OPSAS | 36 |
| KCSAS | 37 |
| KSSAS | 38 |
| TCSAS | 39 |
| TSSAS | 40 |
| ITERT | 41 |
| OPLMDA | 42 |

STDATA(251)

| | |
|------------|-----|
| NPRNTP | 1 |
| NPRNTL | 2 |
| ITERS | 3 |
| CPLMDA | 4 |
| DELTA | 5 |
| DOF(7) | 6 |
| CCN(16) | 13 |
| GUS(3) | 29 |
| CPPRNT(4) | 32 |
| KCSAS | 36 |
| KSSAS | 37 |
| TCSAS | 38 |
| TSSAS | 39 |
| EQTYPE(12) | 40 |
| NPRNTT | 52 |
| ANTYPE(5) | 53 |
| NSYSAN | 58 |
| NSTEP | 59 |
| NFREQ | 60 |
| FREQ(100) | 61 |
| NBPLOT | 161 |
| NAMEXP(7) | 162 |
| NAMEVP(19) | 169 |
| NXPLT | 188 |
| NVPLT | 189 |
| NDPLT | 190 |
| NFOPLT | 191 |
| NF1PLT | 192 |
| MSPLT | 193 |
| NTPLOT | 194 |
| PERPLT | 195 |
| DTPLT | 196 |
| TMXPLT | 197 |
| LGUST(3) | 198 |
| MGUST(3) | 201 |
| NAMEXA(10) | 204 |
| FREQA(10) | 214 |
| MACC | 224 |
| FSACC | 225 |
| BLACC | 226 |
| WLACC | 227 |
| TSTEP | 228 |
| TMAX | 229 |
| OPPLOT | 230 |
| DOFPLT(21) | 231 |

FLDATA(566)

| | |
|------------|-----|
| OPFLOW | 1 |
| OPSYMM | 2 |
| OPFDAN | 3 |
| MPSIPC | 4 |
| NINTPC | 5 |
| NBLDFL | 6 |
| OPSAS | 7 |
| KCSAS | 8 |
| KSSAS | 9 |
| TCSAS | 10 |
| TSSAS | 11 |
| OPTORS(2) | 12 |
| OPGRND | 14 |
| KASGE | 15 |
| DOF(80) | 16 |
| CON(26) | 96 |
| GUS(3) | 122 |
| DELTA | 125 |
| OPRINT | 126 |
| MPSICC | 127 |
| DALPHA | 128 |
| DMACH | 129 |
| OPUSLD | 130 |
| ANTYPE(4) | 131 |
| NSYSAN | 135 |
| NSTEP | 136 |
| NFREQ | 137 |
| FREQ(100) | 138 |
| NBPLOT | 238 |
| NAMEXP(80) | 239 |
| NAMEVP(29) | 319 |
| NXPLT | 348 |
| NVPLT | 349 |
| NDPLT | 350 |
| NFOPLT | 351 |
| NF1PLT | 352 |
| MSPLT | 353 |
| NTPLOT | 354 |
| PERPLT | 355 |
| DTPLT | 356 |
| TMXPLT | 357 |
| LGUST(3) | 358 |
| MGUST(3) | 361 |
| NAMEXA(83) | 364 |
| FREQA(83) | 447 |
| MACC | 530 |
| FSACC | 531 |

FLDATA

BLACC
WLACC
ZETACC(3,10)
NAMEXR(3)

532
533
534
564

A1TABL(15119)

| | | |
|-----------|--|-------|
| TITLE(20) | title for airfoil data (80 characters) | 1 |
| IDENT(4) | identification (alphanumeric date and time) | 21 |
| NMAX | $n_{N_a} * n_{N_m} * N_r$ | 25 |
| | angle of attack boundaries | |
| NAB | N_a | 26 |
| NA(20) | $n_k, k = 1 \text{ to } N_a$ | 27 |
| A(20) | $\alpha_k \text{ (deg), } k = 1 \text{ to } N_a$ | 47 |
| | Mach number boundaries | |
| NMB | N_m | 67 |
| NM(20) | $n_k, k = 1 \text{ to } N_m$ | 68 |
| M(20) | $M_k, k = 1 \text{ to } N_m$ | 88 |
| | radial stations | |
| NRB | N_r | 108 |
| R(11) | $r_k, k = 1 \text{ to } N_r+1$ | 109 |
| | airfoil characteristics | |
| CLT(5000) | $c_{l_j}, j = 1 \text{ to } NMAX$ | 120 |
| CDT(5000) | $c_{d_j}, j = 1 \text{ to } NMAX$ | 5120 |
| CMT(5000) | $c_{m_j}, j = 1 \text{ to } NMAX$ | 10120 |

CASECM(9)

| | | |
|--------|--|---|
| RESTRT | restart code: 1 for trim, 2 for flutter, 3 for flight dynamics, 4 for transient | 1 |
| JCASE | case number | 2 |
| TASK | task code: 1 for trim, 2 for flutter, 3 for flight dynamics, 4 for transient | 3 |
| JOB | | 4 |
| RSWRT | | 5 |
| NCASES | | 6 |
| BLKDAT | | 7 |
| RDFILE | | 8 |
| START | | 9 |

UNITNO(11)

| | |
|-------|----|
| NFDAT | 1 |
| NFAF1 | 2 |
| NFAF2 | 3 |
| NFRS | 4 |
| NFEIG | 5 |
| NFSCR | 6 |
| NUDB | 7 |
| NUOUT | 8 |
| NUPP | 9 |
| NULIN | 10 |
| NUIN | 11 |

TRIMCM(1604)

| | | |
|--------------|---|----|
| IDENT(4) | identification code for case and restart file (alphanumeric date and time) | 1 |
| DRATIO | density ratio, ρ/ρ_0 | 5 |
| DENSE | air density ρ | 6 |
| CSOUND | speed of sound | 7 |
| ALTD | density altitude | 8 |
| GRAV | gravity, $g/\Omega^2 R$ | 9 |
| CXTARG | target C_X/σ for trim | 10 |
| OPRTR2 | integer parameter: 0 to skip rotor #2 calculations | 11 |
| DPSI | $\Delta\psi$ (rad) | 12 |
| COUNTT | integer parameter: number of trim iterations | 13 |
| FSCALE | Ω (reference rotor) | 14 |
| RSCALE | R | 15 |
| NSCALE | N | 16 |
| ISCALE | I_b | 17 |
| GSCALE | γ | 18 |
| SSCALE | σ | 19 |
| CSCALE | c_m | 20 |
| COSPSI(36) | $\cos \psi_j$, $j = 1$ to MPSI | 21 |
| SINPSI(36) | $\sin \psi_j$, $j = 1$ to MPSI | 57 |
| KEPSI(21,36) | complex parameter: $(K_n/J)e^{-in\psi_j}$ $j = 1$ to MPSI, $n = 1$ to $\max(MHARM, MHARMF*NBLADE)$ | 93 |

RTR1CM(1070)

| | | |
|-------------|---|-----|
| OMEGA | rotor speed Ω (rad/sec) | 1 |
| MTIP | tip Mach number $\Omega R/c_s$ | 2 |
| GAMMA | Lock number γ | 3 |
| CMEAN | mean chord c_m | 4 |
| IB | characteristic inertia I_b | 5 |
| NBM | number of bending modes | 6 |
| NTM | number of torsion modes | 7 |
| NGM | zero if no gimbal or teeter mode | 8 |
| NBMT | number of mean bending deflection modes | 9 |
| GLAG | ϵ_{lag} | 10 |
| MLD | $M_{LD}/I_b \Omega^2$ | 11 |
| DZLD | \dot{z}_{LD}/Ω | 12 |
| CGC | $C_{GC}^* = C_{GC}/\frac{1}{2}NI_b \Omega$ (or $C_T^* = C_{GC}/2I_b \Omega$) | 13 |
| CGS | $C_{GS}^* = C_{GS}/\frac{1}{2}NI_b \Omega$ | 14 |
| NUGC | ν_{GC} (or ν_T) | 15 |
| NUGS | ν_{GS} | 16 |
| CTO | collective control damping $C_o/I_b \Omega$ | 17 |
| CTC | cyclic control damping $C_o/I_b \Omega$ | 18 |
| CTR | rotating control damping $C_o/I_b \Omega$ | 19 |
| RA(30) | aerodynamic radial stations, r_i , $i = 1$ to MRA | 20 |
| DRA(30) | aerodynamic segment length Δr_i , $i = 1$ to MRA | 50 |
| FTIP(30) | tip loss multiplicative factor f_i , $i = 1$ to MRA | 80 |
| PSI21M | $\Delta\psi_{21}$ (rad), 0. for rotor #1 (for BODYM, MOTNH, WAKEN, ENGNM) | 110 |
| PSI21W | $\Delta\psi_{21}$ (rad), $-\Delta\psi_{21}$ for rotor #2 (for WAKEN, WAKEC) | 111 |
| MUX | μ_x | 112 |
| MUY | μ_y | 113 |
| MUZ | μ_z | 114 |
| RGUST(3,3) | R_G | 115 |
| CHUB(6,16) | c | 124 |
| CBHUB(3,3) | \bar{c} (including factor Ω_{ref}/Ω) | 220 |
| CHUBT(16,6) | c^T | 229 |

| | | RTR1CM |
|------------|--|--------|
| ALFHP | α_{HP} (deg) | 325 |
| PSIHP | ψ_{HP} (deg) | 326 |
| MAT | M_{at} | 327 |
| CD(2) | C_D for drive train H_n^{-1} | 328 |
| CPSI(2) | C_ψ for drive train motion | 330 |
| | burst tip vortex in wake model | |
| PINTER(36) | ϕ_{inter} (rad) at ψ_j , $j = 1$ to MPSI | 332 |
| PBURST(36) | ϕ_b (rad) at ψ_j , $j = 1$ to MPSI | 368 |
| | inertial and structural data at $r = e + (j-1)\Delta r$, $j = 1$ to MRB+1 | |
| EIXXB(51) | $\Omega^2 R^4 / EI_{xx}$ | 404 |
| EIZZB(51) | $\Omega^2 R^4 / EI_{zz}$ | 455 |
| MASSB(51) | m | 506 |
| TWISTB(51) | Θ_{tw} (rad) | 557 |
| CENT(51) | $\int_r^1 m g dg$ | 608 |
| | inertial and structural data at $r = r_{FA} + (j-1)\Delta r$, $j = 1$ to MRB+1 | |
| ITHETB(51) | I_θ | 659 |
| GJB(51) | $\Omega^2 R^4 / GJ$ | 710 |
| | inertial data at $r = (j-1)\Delta r$, $j = 1$ to MRM+1 | |
| MASSI(51) | mR^3 / I_b | 761 |
| ITHETI(51) | $I_\theta R / I_b$ | 812 |
| XII(51) | x_I / R | 863 |
| XCI(51) | x_C / R | 914 |
| TWISTI(51) | Θ_{tw} (rad) | 965 |
| KP2I(51) | k_P^2 / R^2 | 1016 |
| IPITCH | blade pitch inertia (slug-ft ² or kg-m ²) | 1067 |
| | control system stiffness K_θ (ft-lb/rad or m-N/rad) | |
| KTO | collective | 1068 |
| KTC | cyclic | 1069 |
| KTR | reactionless | 1070 |

RH1CM(12792)

| | | |
|----------------|---|-------|
| HRTR(16,16,21) | complex rotor transfer function matrix, H_n^{-1} ; size NBM+NTM+NGM; $n = 0$ to MHARM | 1 |
| HBODY(16,6,10) | complex airframe transfer function matrix, $H_n^{-1} C^T e^{in\Delta\psi_1}$; $n = pN\Omega/\Omega_{ref}$, $p = 1$ to MHARMF | 10753 |
| HENG(6,10) | complex drive train transfer function matrix, $H_n^{-1} C_D e^{in\Delta\psi_1}$; $n = pN\Omega/\Omega_{ref}$, $p = 1$ to MHARMF | 12673 |

BODYCM(446)

| | | |
|--------------|---|-----|
| AMODE1(6,16) | $(\vec{\xi}_k, \vec{\gamma}_k)$ at rotor #1 hub (dimensionless) | 1 |
| AMODE2(6,16) | $(\vec{\xi}_k, \vec{\gamma}_k)$ at rotor #2 hub (dimensionless) | 61 |
| | pitch/mast-bending coupling (dimensionless) | |
| KMSTC1(10) | K_{MC_k} for rotor #1 | 121 |
| KMSTS1(10) | K_{MS_k} for rotor #1 | 131 |
| KMSTC2(10) | K_{MC_k} for rotor #2 | 141 |
| KMSTS2(10) | K_{MS_k} for rotor #2 | 151 |
| ADAMPA(10) | aerodynamic damping $(2\gamma/\sigma aA)(q/V)F_{q_k \dot{q}_k}$ | 161 |
| ACNTRL(4,10) | control derivatives $(2\gamma/\sigma aA)q F_{q_k \delta}$ | 171 |
| AMASS(10) | M_k^* | 211 |
| ADAMPS(10) | $M_k^* g_s \omega_k$ | 221 |
| ASPRNG(10) | $M_k^* \omega_k^2$ | 231 |
| MSTAR | M^* | 241 |
| MSTARG | $M^* g$ | 242 |
| ISTAR(3,3) | I^* | 243 |
| CWS | $C_W/\sigma = (a/2\gamma) M^* g$ | 252 |
| HMASS | aircraft mass (slug or kg) | 253 |
| NAM | number of airframe modes | 254 |
| | aircraft description ($\partial_T = \psi_T = 0$) | |
| RSF10(3,3) | R_{SF} for rotor #1 | 255 |
| RSF20(3,3) | R_{SF} for rotor #2 | 264 |
| RHUB10(3) | \vec{r} at rotor #1 hub | 273 |
| RHUB20(3) | \vec{r} at rotor #2 hub | 276 |
| RWB0(3) | \vec{r} at wing/body | 279 |
| RHT0(3) | \vec{r} at horizontal tail | 282 |
| RVTO(3) | \vec{r} at vertical tail | 285 |
| ROFF0(3) | \vec{r} off rotor | 288 |

| | aircraft description | BODYCM |
|-------------|----------------------------------|--------|
| RSF1(3,3) | R_{SF} for rotor #1 | 291 |
| RSF2(3,3) | R_{SF} for rotor #2 | 300 |
| RHUB1(3) | \vec{r} at rotor #1 hub | 309 |
| RHUB2(3) | \vec{r} at rotor #2 hub | 312 |
| RWB(3) | \vec{r} at wing/body | 315 |
| RHT(3) | \vec{r} at horizontal tail | 318 |
| RVT(3) | \vec{r} at vertical tail | 321 |
| ROFF(3) | \vec{r} off rotor | 324 |
| TCFE(11,5) | T_{CFE} | 327 |
| VXREKF(3) | $(\vec{V} \times) R_e \vec{k}_F$ | 382 |
| MXRE(3,3) | $-M^* (\vec{V} \times) R_e$ | 385 |
| GMTRX(3,3) | G | 394 |
| IBODY(3,3) | $R_e^T I^* R_e$ | 403 |
| REULER(3,3) | R_e | 412 |
| RFV(3,3) | R_{FV} | 421 |
| RFE(3,3) | R_{FE} | 430 |
| KE(3) | \vec{k}_E | 439 |
| VELF(3) | \vec{V} | 442 |
| VCLIMB | v_{climb} | 445 |
| VSIDE | v_{side} | 446 |

ENGNCM(131)

| | | |
|------------|---|-----|
| QTHRTL | $r_{E t}^{Q*}$ | 1 |
| IENG | $r_E^2 I_E^*$ | 2 |
| KMI1 | K_{MI1} | 3 |
| KMI2 | K_{MI2}^* | 4 |
| KMR | K_{MR}^* | 5 |
| KME1 | K_{ME1}^* | 6 |
| KME2 | K_{ME2}^* | 7 |
| KPGOVE | governor proportional gains, $K_p^* \Omega$ engine | 8 |
| KPGOV1 | rotor #1 | 9 |
| KPGOV2 | rotor #2 | 10 |
| NDM | number of drive train modes | 11 |
| T1GOVE | governor time lag, $\tau_1^* \Omega$ engine | 12 |
| T1GOV1 | rotor #1 | 13 |
| T1GOV2 | rotor #2 | 14 |
| T2GOVE | governor time lag, $\tau_2^* \Omega^2$ engine | 15 |
| T2GOV1 | rotor #1 | 16 |
| T2GOV2 | rotor #2 | 17 |
| QEDAMP | $r_E^2 Q_{\Omega}^*$ | 18 |
| IRSTAR | I_R^* | 19 |
| MENG(6,6) | mass matrix for H_n^{-1} | 20 |
| SENG(6,6) | spring matrix for H_n^{-1} | 56 |
| DENG(6,6) | damping matrix for H_n^{-1} | 92 |
| HENG0(2,2) | H_0^{-1} for static elastic motion | 128 |

GUSTCM(12989)

| | | |
|--------------------------------|---|-------|
| gust components, velocity axes | | |
| VGWBV(3) | at wing/body, \vec{g}_w | 1 |
| VGHTV(3) | at horizontal tail, \vec{g}_H | 4 |
| VGVTV(3) | at vertical tail, \vec{g}_V | 7 |
| VGR1V(3,30,36) | at rotor #1, $\vec{g}(r_1, \psi_j)$ | 10 |
| VGR2V(3,30,36) | at rotor #2, $\vec{g}(r_1, \psi_j)$ | 3250 |
| VGHUB1(3) | at rotor #1 hub, \vec{g} (for wake geometry) | 6490 |
| VGHUB2(3) | at rotor #2 hub, \vec{g} (for wake geometry) | 6493 |
| gust components, F axes | | |
| VGWBF(3) | at wing/body, \vec{g}_w | 6496 |
| VGHTF(3) | at horizontal tail, \vec{g}_H | 6499 |
| VGVTF(3) | at vertical tail, \vec{g}_V | 6502 |
| gust components, S axes | | |
| VGR1S(3,30,36) | at rotor #1, $\vec{g}(r_1, \psi_j)$ | 6505 |
| VGR2S(3,30,36) | at rotor #2, $\vec{g}(r_1, \psi_j)$ | 9745 |
| transient control | | |
| VPTRAN(5) | $\Delta \vec{v}_p = (\delta_0 \delta_c \delta_s \delta_p \delta_t)^T$ | 12985 |

CONTCM(32)

| | | |
|------------|--|----|
| VCNTRL(11) | control vector (rad): $\vec{v} = (\theta_{r1}, \theta_{r2}, \theta_{a1}, \theta_{a2}, \theta_{a3}, \delta_1, \delta_2, \delta_3, \delta_4, \delta_5)^T$ <div style="display: flex; justify-content: space-around; margin-top: -10px;"> rotor#1 rotor#2 airframe </div> | 1 |
| THETFT | θ_{FT} (rad) | 12 |
| PHIFT | ϕ_{FT} (rad) | 13 |
| THETFP | θ_{FP} (rad) | 14 |
| PSIFP | ψ_{FP} (rad) | 15 |
| THETAT | θ_T (rad) | 16 |
| PSIT | ψ_T (rad) | 17 |
| DVBODY(6) | airframe motion (dimensionless) $(\dot{\phi}_F, \dot{\theta}_F, \dot{\psi}_F, \dot{x}_F, \dot{y}_F, \dot{z}_F)$ | 18 |
| DOMEGA | $\dot{\psi}_s$ (static; dimensionless) | 24 |
| DDZF | \ddot{z}_F (dimensionless) | 25 |
| VPILOT(5) | pilot control vector (rad): $\vec{v}_p = (\delta_0, \delta_c, \delta_s, \delta_p, \delta_t)^T$ | 26 |
| TGOVR1 | $(\Delta \theta_{govr})_{rotor\#1}$ (rad) | 31 |
| TGOVR2 | $(\Delta \theta_{govr})_{rotor\#2}$ (rad) | 32 |

CONVCM(80)

| | | |
|----------|---|----|
| | mean square motion (rotor #1) | |
| B1MS(10) | β | 1 |
| T1MS(5) | θ | 11 |
| BG1MS | β_G | 16 |
| P1MS(16) | ϕ | 17 |
| PS1MS(6) | ψ | 33 |
| | mean square motion (rotor #2) | |
| B2MS(10) | β | 39 |
| T2MS(5) | θ | 49 |
| BG2MS | β_G | 54 |
| P2MS(16) | ϕ | 55 |
| PS2MS(6) | ψ | 71 |
| G1MS | mean square circulation (rotor #1) | 77 |
| G2MS | mean square circulation (rotor #2) | 78 |
| COUNTM | integer parameter: number of motion iterations | 79 |
| COUNTC | integer parameter: number of circulation iterations | 80 |

MD1CM(6773)

| | | |
|----------------|---|------|
| T75OLD | old θ_{75} (initialized to 1000.) | 1 |
| NBMOLD | old NBM (initialized to 0) | 2 |
| NTMOLD | old NTM (initialized to 0) | 3 |
| NU(20) | bending frequency ν_1 , $i = 1$ to NCOLB (per rev) | 4 |
| NUNR(20) | nonrotating bending frequency ν_{NR1} , $i = 1$ to NCOLB (rad/sec) | 24 |
| | bending mode displacement $\vec{\eta}_1$, $i = 1$ to NBM, at radial station $r =$ | |
| ETA(2,10) | r_{FA} | 44 |
| ETA(2,10) | r_{PB} | 64 |
| ETA(2,10) | r_{ROOT} | 84 |
| ETA(2,10) | 1 | 104 |
| ETA(2,10,11) | $(j-1)0.1$, $j = 1$ to 11 | 124 |
| ETA(2,10,51) | $(j-1)\Delta r$, $j = 1$ to MRM+1 | 344 |
| ETA(2,10,30) | r_j , $j = 1$ to MRA | 1364 |
| | bending mode slope $\vec{\eta}'_1$, $i = 1$ to NBM, at radial station $r =$ | |
| ETAP(2,10) | r_{FA} | 1964 |
| ETAP(2,10) | r_{PB} | 1984 |
| ETAP(2,10) | r_{ROOT} | 2004 |
| ETAP(2,10) | 1 | 2024 |
| ETAP(2,10,11) | $(j-1)0.1$, $j = 1$ to 11 | 2044 |
| ETAP(2,10,51) | $(j-1)\Delta r$, $j = 1$ to MRM+1 | 2264 |
| ETAP(2,10,30) | r_j , $j = 1$ to MRA | 3284 |
| | bending mode curvature $\vec{\eta}''_1$, $i = 1$ to NBM, at radial station $r =$ | |
| ETAPP(2,10) | r_{FA} | 3884 |
| ETAPP(2,10) | r_{PB} | 3904 |
| ETAPP(2,10) | r_{ROOT} | 3924 |
| ETAPP(2,10) | 1 | 3944 |
| ETAPP(2,10,11) | $(j-1)0.1$, $j = 1$ to 11 | 3964 |
| ETAPP(2,10,51) | $(j-1)\Delta r$, $j = 1$ to MRM+1 | 4184 |
| ETAPP(2,10,30) | r_j , $j = 1$ to MRA | 5204 |

| | | |
|-------------|--|-------|
| | | MD1CM |
| ETAPH(2,10) | bending mode slope at hinge, $\vec{\eta}'(e)$ | 5804 |
| WT(11) | torsion frequency ω_1 , $i = 1$ to NCOLT+1, (per rev) | 5824 |
| | control system frequency (per rev) | |
| WTO | collective | 5835 |
| WTC | cyclic | 5836 |
| WTR | reactionless | 5837 |
| | torsion mode displacement ξ_1 , $i = 1$ to NTM, at radial station $r =$ | |
| ZETA(5,11) | $(j-1)0.1$, $j = 1$ to 11 | 5838 |
| ZETA(5,51) | $(j-1)\Delta r$, $j = 1$ to MRM+1 | 5893 |
| ZETA(5,30) | r_j , $j = 1$ to MRA | 6148 |
| | torsion mode slope ξ'_1 , $i = 1$ to NTM, at radial station $r =$ | |
| ZETAP(5,11) | $(j-1)0.1$, $j = 1$ to 11 | 6298 |
| ZETAP(5,51) | $(j-1)\Delta r$, $j = 1$ to MRM+1 | 6353 |
| ZETAP(5,30) | r_j , $j = 1$ to MRA | 6608 |
| KPB(10) | pitch/bending coupling K_{P_1} , $i = 1$ to NBM | 6758 |
| KPG | pitch/gimbal coupling K_{P_G} | 6768 |
| DEL1 | δ_{FA_1} (rad) | 6769 |
| DEL2 | δ_{FA_2} (rad) | 6770 |
| DEL3 | δ_{FA_3} (rad) | 6771 |
| DEL4 | δ_{FA_4} (rad) | 6772 |
| DEL5 | δ_{FA_5} (rad) | 6773 |

INC1CM(4365)

| | | |
|-----------------|--|------|
| MB | Inertia coefficients | 1 |
| SB | | 2 |
| IO | | 3 |
| IQ(10) | | 4 |
| SQ(2,10) | | 14 |
| IQA(2,10) | | 34 |
| IQDQ(10,10) | | 54 |
| IQDQT(10,10,4) | | 154 |
| IQDP(10) | | 554 |
| IQDPT(10,4) | | 564 |
| IQDB(10) | | 604 |
| IQDBT(10,4) | | 614 |
| SQDDP(10,5) | | 654 |
| SQDDPT(10,5,4) | | 704 |
| SQP(10,5) | | 904 |
| SQPT(10,5,4) | | 954 |
| IQO(10) | | 1154 |
| IQODQ(2,10) | | 1164 |
| IQODQT(2,10,4) | | 1184 |
| IQODP | | 1264 |
| IQODPT(4) | | 1265 |
| IQODB | | 1269 |
| IQODBT(4) | | 1270 |
| SQODDP(2,5) | | 1274 |
| SQODDT(2,5,4) | | 1284 |
| IFXO | | 1324 |
| IMXO | | 1325 |
| IP(5) | | 1326 |
| IPA(2,5) | | 1331 |
| IPAT(2,5,4) | | 1341 |
| SP(2,5) | | 1381 |
| SPT(2,5,4) | | 1391 |
| IPDDP(5,5) | | 1431 |
| IPDDPT(5,5,4) | | 1456 |
| IPDDTT(5,5,4,4) | | 1556 |
| IPP(5,5) | | 1956 |
| SPDDQ(5,10) | | 1981 |
| SPDDQT(5,10,4) | | 2031 |
| IPO(5) | | 2231 |
| SPQ(5,10) | | 2236 |
| SPQT(5,10,4) | | 2286 |
| XAPQ(2,5,4,30) | \vec{X}_{kj} at r_1 , $i = 1$ to MRA | 2486 |
| MQDQ(10,10) | Aerodynamic spring and damping | 3686 |
| MQDB(10) | | 3786 |
| MQP(10,5) | | 3796 |
| MDQ(10) | | 3846 |
| MDB | | 3856 |
| MP(5) | | 3857 |

| | | INC1CM |
|--------------|---|--------|
| QDZ | | 3862 |
| QT | | 3863 |
| MPDQ(5,10) | | 3864 |
| MPDB(5) | | 3914 |
| MPDP(5,5) | | 3919 |
| MPP(5,5) | | 3944 |
| IQDQS(10,10) | Inertia coefficients, summed over q_j | 3969 |
| IQDPS(10) | | 4069 |
| IQDBS(10) | | 4079 |
| SQDDPS(10,5) | | 4089 |
| SQPS(10,5) | | 4139 |
| IQODQS(2,10) | | 4189 |
| IQODPS | | 4209 |
| IQODBS | | 4210 |
| SQODDS(2,5) | | 4211 |
| IPAS(2,5) | | 4221 |
| SPS(2,5) | | 4231 |
| IPDDPS(5,5) | | 4241 |
| SPDDQS(5,10) | | 4266 |
| SPQS(5,10) | | 4316 |

(NBM=10, NTM=5, NBMT=4, MRA=30)

WKV1CM(8165)

| | | |
|---------------|---|------|
| CTOLD | old C_T | 1 |
| CMXOLD | old C_{M_x} | 2 |
| CMYOLD | old C_{M_y} | 3 |
| GAMOLD(30,36) | old Γ_{ij} ($i = 1$ to MRA, $j = 1$ to MPSI) | 4 |
| CRCOLD(36) | old max Γ_j ($j = 1$ to MPSI) | 1084 |
| VIND(3,30,36) | $\vec{\lambda}(r_i, \psi_j)$ ($i = 1$ to MRA, $j = 1$ to MPSI) | 1120 |
| LAMBDA | mean λ_{tpp} | 4360 |
| FGE | $f_{GE} = v/v_\infty = 1 - (\cos \epsilon / 4z)^2$ (1. if OGE) | 4361 |
| COSE | $\cos \epsilon$ | 4362 |
| ZAGL | z_{AGL} | 4363 |
| VINT(3,30,36) | $\vec{\lambda}_{int}(r_i, \psi_j)$ ($i = 1$ to MRA, $j = 1$ to MPSI) at other rotor | 4364 |
| VORH(3,36) | $\vec{\lambda}_{int}(\psi_j)$ ($j = 1$ to MPSI), at other rotor hub | 7604 |
| LAMBDI | mean λ_{int} , at other rotor | 7712 |
| VWB(3,36) | $\vec{\lambda}_W(\psi_j)$ ($j = 1$ to MPSI), at wing/body | 7713 |
| VHT(3,36) | $\vec{\lambda}_H(\psi_j)$ ($j = 1$ to MPSI), at horizontal tail | 7821 |
| VVT(3,36) | $\vec{\lambda}_V(\psi_j)$ ($j = 1$ to MPSI), at vertical tail | 7929 |
| VOFF(3,36) | $\vec{\lambda}_O(\psi_j)$ ($j = 1$ to MPSI), off rotor disk | 8037 |
| LAMBDW(3) | mean $\vec{\lambda}_W$, at wing/body | 8145 |
| LAMBDH(3) | mean $\vec{\lambda}_H$, at horizontal tail | 8148 |
| LAMBDV(3) | mean $\vec{\lambda}_V$, at vertical tail | 8151 |
| LAMBDO(3) | mean $\vec{\lambda}_O$, off rotor disk | 8154 |
| EINTW(3) | $\vec{e}_W = K_W C_{R_{SF}}^T (-\vec{k}_S)(\Omega R)/(\Omega R)_{ref}$ | 8157 |
| EINTH(3) | $\vec{e}_H = K_H C_{R_{SF}}^T (-\vec{k}_S)(\Omega R)/(\Omega R)_{ref}$ | 8160 |
| EINTV(3) | $\vec{e}_V = K_V C_{R_{SF}}^T (-\vec{k}_S)(\Omega R)/(\Omega R)_{ref}$ | 8163 |

MNH1CM(462)

| | | |
|-------------|--|-----|
| ALF(10,6) | complex α_{pN} (p = 1 to MHARMF), without Euler angle contributions | 1 |
| DALF(10,6) | complex $\dot{\alpha}_{pN}$ (p = 1 to MHARMF) | 121 |
| DDALF(10,6) | complex $\ddot{\alpha}_{pN}$ (p = 1 to MHARMF) | 241 |
| PSIS(10) | complex ψ_{spN} (p = 1 to MHARMF) | 361 |
| TGOVR(10) | complex $(\Delta\Theta_{govr})_{pN}$ (p = 1 to MHARMF) | 381 |
| TMAST(21) | complex $(\Delta\Theta_{mast-bend})_n$ (n = 1 to MHARM) | 401 |
| ALFO(6) | α_{static} | 443 |
| DDALO(6) | $\dot{\alpha}_{static}$ | 449 |
| DDALFO(6) | $\ddot{\alpha}_{static}$ | 455 |
| PSISO | $(\psi_s)_{static}$ | 461 |
| DPSISO | $(\dot{\psi}_s)_{static}$ | 462 |

$$\alpha = (x_h \ y_h \ z_h \ \alpha_x \ \alpha_y \ \alpha_z)^T$$

AES1CM(36720)

| | | |
|----------------|---|-------|
| STATE(30,36,3) | integer parameter defining stall state for lift, drag, moment (initialized to zero) | 1 |
| | peak dynamic stall vortex loads (initialized to zero) | |
| DCLMAX(30,36) | $c_{l_{max}}$ | 3241 |
| DCDMAX(30,36) | $c_{d_{max}}$ | 4321 |
| DCMMAX(30,36) | $c_{m_{max}}$ | 5401 |
| | effective environment for lift, drag, moment | |
| MEFF(30,36,3) | Mach number M_{eff} | 6481 |
| AEFF(30,36,3) | angle of attack α_{eff} | 9721 |
| | dynamic stall vortex load | |
| DCLDS(30,36) | $c_{l_{ds}}$ | 12961 |
| DCDDS(30,36) | $c_{d_{ds}}$ | 14041 |
| DCMDS(30,36) | $c_{m_{ds}}$ | 15121 |
| SAVE(30,36,19) | section aerodynamic data | 16201 |
| | (1) u_P (11) c_{λ} | |
| | (2) u_T (12) c_d | |
| | (3) u_R (13) c_m | |
| | (4) U (14) $c_{d_{radial}}$ | |
| | (5) Θ (deg) (15) F_x/ac_m | |
| | (6) ϕ (deg) (16) F_r/ac_m | |
| | (7) α (deg) (17) F_z/ac_m | |
| | (8) M (18) M_a/ac_m | |
| | (9) $\cos \Lambda$ (19) F_r/ac_m | |
| | (10) $\dot{\alpha}c/V$ | |

aerodynamic data at (r_i, ψ_j) on disk,
 $i = 1$ to MRA, $j = 1$ to MPSI

MNR1CM(1112)

| | | |
|-------------|--|-----|
| BETA(21,10) | complex $\beta_n^{(i)}$ ($i = 1$ to NBM, $n = 0$ to MHARM) | 1 |
| THETA(21,5) | complex $\Theta_n^{(i)}$ ($i = 1$ to NTM, $n = 0$ to MHARM) | 421 |
| BETAG(21) | complex β_{G_n} ($n = 0$ to MHARM) | 631 |
| PHI(10,16) | complex $\Phi_{pN}^{(i)}$ ($i = 1$ to NAM, $p = 1$ to MHARMF) | 673 |
| PSID(10,6) | complex $(\psi_s \psi_I \psi_e \Delta\theta_t \Delta\theta_{g_1} \Delta\theta_{g_2})_{pN}$ ($p = 1$ to MHARMF) | 993 |

MNSCM(12)

| | | | |
|------------|---|----------------|----|
| QSSTAT(10) | $(q_{s_k})_{\text{static}}$ elastic | (k = 7 to NAM) | 1 |
| PISTAT | $(\psi_I)_{\text{static}}$ elastic | | 11 |
| PESTAT | $(\psi_e)_{\text{static}}$ elastic | | 12 |

AEF1CM(1548)

| | | |
|--------------|---|-----|
| FORCE(16,36) | (\vec{F}_j) last rev, $j = 1$ to MPSI (dimension NBM+NTM+NGM) | 1 |
| FHUB(6,36) | hub reactions (without rotor mass terms) $F = (\delta 2C_H/\sigma a, \delta 2C_Y/\sigma a, \delta 2C_T/\sigma a,$ $\delta 2C_{M_x}/\sigma a, \delta 2C_{M_y}/\sigma a, -\delta 2C_Q/\sigma a)$ | 577 |
| TORQUE(36) | $\delta \tilde{C}_Q/\sigma a$ | 793 |
| SAVE(36,20) | integrated aerodynamic forces (1)-(10) $M_{q_k} \text{aero}/ac$ (11)-(15) $M_{p_k} \text{aero}/ac$ (16) $C_{m_x}/\sigma a$ (17) $C_{m_z}/\sigma a$ (18) $C_{f_x}/\sigma a$ (19) $C_{f_z}/\sigma a$ (20) $C_{f_r}/\sigma a$ | 829 |

QR1CM(1139)

| | | |
|------------|--|------|
| QRTR(6) | rotor generalized force, $\vec{Q} = c^T F$ | 1 |
| FHUBM(6) | mean hub reaction $F = (\delta 2C_H/\sigma a, \delta 2C_Y/\sigma a, \delta 2C_T/\sigma a, \delta 2C_{M_x}/\sigma a, \delta 2C_{M_y}/\sigma a, -\delta 2C_Q/\sigma a)$ | 7 |
| | for trim | |
| CLS | C_L/σ (wind axes) | 13 |
| CXS | C_X/σ (wind axes) | 14 |
| CTS | C_T/σ | 15 |
| CYS | C_Y/σ | 16 |
| CPS | C_P/σ | 17 |
| | for inflow | |
| CT | C_T | 18 |
| CMX | C_{M_x} | 19 |
| CMY | C_{M_y} | 20 |
| | for trim | |
| BETA0 | β_0 | 21 |
| BETAC | β_c | 22 |
| BETAS | β_s | 23 |
| | for inflow | |
| GAM(30,36) | circulation Γ_{ij} ($i = 1$ to MRA, $j = 1$ to MPSI) | 24 |
| CIRC(36) | maximum circulation Γ_j ($j = 1$ to MPSI) | 1104 |

QBDCM(49)

| | | |
|----------|------------------------------------|---------------------|
| QWB(6) | wing-body generalized forces | 1 |
| QHT(6) | horizontal tail generalized forces | 7 |
| QVT(6) | vertical tail generalized forces | 13 |
| SAVE(31) | airframe aerodynamic data | 19 |
| (1) | $(D/q)_{WB}$ | ft^2 or m^2 |
| (2) | $(Y/q)_{WB}$ | |
| (3) | $(L/q)_{WB}$ | |
| (4) | $(M_x/q)_{WB}$ | ft^3 or m^3 |
| (5) | $(M_y/q)_{WB}$ | |
| (6) | $(M_z/q)_{WB}$ | |
| (7) | $(D/q)_{HT}$ | ft^2 or m^2 |
| (8) | $(L/q)_{HT}$ | |
| (9) | $(D/q)_{VT}$ | |
| (10) | $(L/q)_{VT}$ | |
| (11) | α_{WB} | deg |
| (12) | β_{WB} | |
| (13) | α_{HT} | |
| (14) | α_{VT} | |
| (15) | ϵ | |
| (16) | ρ | |
| (17-19) | V_{WB} | ft/sec or m/sec |
| (20-22) | V_{HT} | |
| (23-25) | V_{VT} | |
| (26-28) | Ω | rad/sec |
| (29) | q_{WB} | dimensionless |
| (30) | q_{HT} | |
| (31) | q_{VT} | |

WG1CM(7998)

| | | |
|--------------|--|------|
| RBR(3,36) | $r_b(r_{\text{ROOT}}, \psi_j)$ | 1 |
| RBT(3,36) | $r_b(1, \psi_j)$ | 109 |
| MUTPP(3) | λ_{tpp} | 217 |
| | prescribed wake, tip vortices | |
| DZT(144) | $D_z(k), k = 1 \text{ to KRWG}$ | 220 |
| DRT(144) | $D_r(k), k = 1 \text{ to KRWG}$ | 364 |
| K2T | K_2 | 508 |
| | prescribed wake, sheet inside edge | |
| DZSI(144) | $D_z(k), k = 1 \text{ to KRWG}$ | 509 |
| DRSI(144) | $D_r(k), k = 1 \text{ to KRWG}$ | 653 |
| K2SI | K_2 | 797 |
| | prescribed wake, sheet outside edge | |
| DZSO(144) | $D_z(k), k = 1 \text{ to KRWG}$ | 798 |
| DRSO(144) | $D_r(k), k = 1 \text{ to KRWG}$ | 942 |
| K2SO | K_2 | 1086 |
| | free wake, tip vortices | |
| DFWG(3,2304) | $\vec{D}(n), n = 1 \text{ to KRWG*MPSI}$ | 1087 |

$$n = (\lambda - 1)KFWG + k$$

$$((k = 1 \text{ to KFWG}), \lambda = 1 \text{ to MPSI})$$

WKC1CM(120007)

| | | |
|--------------|---|-------|
| MR | total number of points in flow field at which nonuniform induced velocity calculated for each azimuth (ML+MI+MW+MH+MV+MO) | 1 |
| ML | number of points on this rotor (MRL if INFLOW(1) = 1; zero otherwise) | 2 |
| MI | number of points on other rotor (MRL of other rotor if INFLOW(2) = 3; 1 if INFLOW(2) = 2; zero otherwise) | 3 |
| MW | number of points on wing-body (1 if INFLOW(3) = 2; zero otherwise) | 4 |
| MH | number of points on horizontal tail (1 if INFLOW(4) = 2; zero otherwise) | 5 |
| MV | number of points on vertical tail (1 if INFLOW(5) = 2; zero otherwise) | 6 |
| MO | number of points off rotor disk (1 if INFLOW(6) = 1; zero otherwise) | 7 |
| C(3,20000) | $\vec{C}(n)$, $n = 1$ to MPSI*MR*MPSI | 8 |
| CNW(3,20000) | $\vec{C}_{NW}(n_{NW})$, $n_{NW} = 1$ to MRG*(KNW+1)*MRL*MPSI | 60008 |

$$\vec{v}(r_k, \psi_k) = \sum_{j=1}^J \Gamma_j \vec{C}(n) + \sum_{j=L-K_{NW}}^L \sum_{i=1}^M \Gamma_{ij} \vec{C}_{NW}(n_{NW})$$

$$n = ((L - 1)*MR + k - 1)*MPSI + j$$

$$(((j = 1 \text{ to } MPSI), k = 1 \text{ to } MR), L = 1 \text{ to } MPSI)$$

$$n_{NW} = (((L - 1)*MRL + k - 1)*(KNW+1) + j - L + KNW)*MRG + 1$$

$$((((i = 1 \text{ to } MRG), j = L - KNW \text{ to } L),$$

$$k = 1 \text{ to } MRL), L = 1 \text{ to } MPSI)$$

AEMNCM(78)

| | | |
|-----------|---|----|
| Q(10) | $q_k, k = 1 \text{ to NBM}$ | 1 |
| DQ(10) | \dot{q}_k | 11 |
| DDQ(10) | \ddot{q}_k | 21 |
| P(5) | $p_k, k = 1 \text{ to NTM } (p_0 = p_d + p_r)$ | 31 |
| DP(5) | \dot{p}_k | 36 |
| DDP(5) | \ddot{p}_k | 41 |
| PD | p_d | 46 |
| DPD | \dot{p}_d | 47 |
| DDPD | \ddot{p}_d | 48 |
| PR | p_r | 49 |
| DPR | \dot{p}_r | 50 |
| DDPR | \ddot{p}_r | 51 |
| BG | β_G | 52 |
| DBG | $\dot{\beta}_G$ | 53 |
| DDBG | $\ddot{\beta}_G$ | 54 |
| AHUB(6) | $\alpha = (x_h \ y_h \ z_h \ \alpha_x \ \alpha_y \ \alpha_z)$ (without Euler angle contributions to $\alpha_x \ \alpha_y \ \alpha_z$) | 55 |
| DAHUB(6) | $\dot{\alpha} = (\dot{x}_h \ \dot{y}_h \ \dot{z}_h \ \dot{\alpha}_x \ \dot{\alpha}_y \ \dot{\alpha}_z)$ | 61 |
| DDAHUB(6) | $\ddot{\alpha} = (\ddot{x}_h \ \ddot{y}_h \ \ddot{z}_h \ \ddot{\alpha}_x \ \ddot{\alpha}_y \ \ddot{\alpha}_z)$ | 67 |
| PS | ψ_s | 73 |
| DPS | $\dot{\psi}_s$ | 74 |
| DDPS | $\ddot{\psi}_s$ | 75 |
| TM | $\Delta\theta_{\text{mast-bend}}$ | 76 |
| TG | $\Delta\theta_{\text{govr}}$ | 77 |
| DTT | $\ddot{\theta}_G - \theta_G + 2\dot{\beta}_G$ | 78 |

LDMNCM(2932)

| | | |
|--------------|---|------|
| SAVEM(36,78) | motion at ψ_j , $j = 1$ to MPSI (refer to common block AEMNCM for contents) | 1 |
| MB | inertial coefficients for section loads | 2809 |
| SB | | 2810 |
| IO | | 2811 |
| SQ(2,10) | | 2812 |
| IQA(2,10) | | 2832 |
| IQDQ(2,10) | | 2852 |
| IQDB | | 2872 |
| IQDP(2) | | 2873 |
| SQDDP(2,5) | | 2875 |
| SQP(2,5) | | 2885 |
| IFX0 | | 2895 |
| IMX0(2) | | 2896 |
| IPDDP(5) | | 2898 |
| IPP(5) | | 2903 |
| IPA(2) | | 2908 |
| SPDDQ(10) | | 2910 |
| SPQ(10) | | 2920 |
| SP(2) | | 2930 |
| IPO | | 2932 |

FLMCM(21928)

| | | |
|------------|------------------------|-------|
| A2(6400) | | 1 |
| A1(6400) | | 6401 |
| A0(6400) | | 12801 |
| B(2320) | | 19201 |
| DOF1(80) | | 21521 |
| NAMEX(80) | | 21601 |
| NAMEV(29) | | 21681 |
| MX | | 21710 |
| MX1 | | 21711 |
| MV | | 21712 |
| MG | | 21713 |
| DOF1S(46) | symmetric matrices | 21714 |
| NAMEXS(46) | | 21760 |
| NAMEVS(16) | | 21806 |
| MXS | | 21822 |
| MX1S | | 21823 |
| MVS | | 21824 |
| MGS | | 21825 |
| DOF1A(43) | antisymmetric matrices | 21826 |
| NAMEXA(43) | | 21869 |
| NAMEVA(13) | | 21912 |
| MXA | | 21925 |
| MX1A | | 21926 |
| MVA | | 21927 |
| MGA | | 21928 |

variables (80)

$$x = (x_{R1} \ x_{R2} \ x_S \ \psi_e \ \Delta\theta_t \ \Delta\theta_{govr1} \ \Delta\theta_{govr2})$$

controls (29)

$$v = (v_{R1} \ v_{R2} \ v_S \ \theta_t \ v_P \ g)$$

FLM1CM(4236)

| | | |
|-----------|---------------|------|
| A2(30,30) | A_2 | 1 |
| A1(30,30) | A_1 | 901 |
| A0(30,30) | A_0 | 1801 |
| AA2(30,6) | \tilde{A}_2 | 2701 |
| AA1(30,6) | \tilde{A}_1 | 2881 |
| AA0(30,6) | \tilde{A}_0 | 3061 |
| B(30,8) | B | 3241 |
| BG(30,3) | B_G | 3481 |
| C2(6,30) | C_2 | 3571 |
| C1(6,30) | C_1 | 3751 |
| C0(6,30) | C_0 | 3931 |
| CA2(6,6) | \tilde{C}_2 | 4111 |
| CA1(6,6) | \tilde{C}_1 | 4147 |
| CA0(6,6) | \tilde{C}_0 | 4183 |
| DG(6,3) | D_G | 4219 |

variables (30): x_R

controls (8): v_R

gust(3): g

hub motion (6): α

hub forces (6): F

FLMACM(912)

| | | |
|-----------|-------------|-----|
| A2(16,16) | a_2 | 1 |
| A1(16,16) | a_1 | 257 |
| A0(16,16) | a_0 | 513 |
| B(16,4) | b | 769 |
| BG(16,3) | b_G | 833 |
| BL(16,2) | b_λ | 881 |

variables (16): x_S
controls (4): v_S
gust (3): g
inflow(2): $(\lambda_u, \lambda_{u_z})$

FLINCM(477)

| | |
|-------------|-----|
| MASSB | 1 |
| IO | 2 |
| IQ(10) | 3 |
| SQ(10,2) | 13 |
| IQA(10,2) | 33 |
| IQDQ(10,10) | 53 |
| IQDP(10) | 153 |
| IQIB(10) | 163 |
| SQDDP(10,5) | 173 |
| SQP(10,5) | 223 |
| IQODQ(10,2) | 273 |
| SQODDP(5,2) | 293 |
| IP(5) | 303 |
| IPA(5,2) | 308 |
| SP(5,2) | 318 |
| IPDDP(5,5) | 328 |
| IPP(5,5) | 353 |
| SPDDQ(5,10) | 378 |
| SPQ(5,10) | 428 |

FLAECM(646)

| | |
|-------------|-----|
| MQU(10) | 1 |
| MQDZ(10) | 11 |
| MQZ(10) | 21 |
| SQL(10) | 31 |
| MQDB(10) | 41 |
| MQB(10) | 51 |
| MQDQ(10,10) | 61 |
| MQQ(10,10) | 161 |
| MQP(10,5) | 261 |
| MMU | 311 |
| MDZ | 312 |
| MZ | 313 |
| ML | 314 |
| MDB | 315 |
| MB | 316 |
| MDQ(10) | 317 |
| MQ(10) | 327 |
| MP(5) | 337 |
| TU | 342 |
| TDZ | 343 |
| TZ | 344 |
| TL | 345 |
| TDB | 346 |
| TB | 347 |
| TDQ(10) | 348 |
| TQ(10) | 358 |
| TP(5) | 368 |
| HU | 373 |
| HDZ | 374 |
| HZ | 375 |
| HL | 376 |
| HDB | 377 |
| HB | 378 |
| HDQ(10) | 379 |
| HQ(10) | 389 |
| HP(5) | 399 |
| QU | 404 |
| QDZ | 405 |
| QZ | 406 |
| QL | 407 |
| QDB | 408 |
| QB | 409 |
| QDQ(10) | 410 |
| QQ(10) | 420 |
| QP(5) | 430 |
| RR | 435 |
| RU | 436 |
| RDZ | 437 |
| RZ | 438 |

FLAECM

| | |
|------------|-----|
| RL | 439 |
| RDB | 440 |
| RB | 441 |
| RDQ(10) | 442 |
| RQ(10) | 452 |
| RP(5) | 462 |
| MPU(5) | 467 |
| MPDZ(5) | 472 |
| MPZ(5) | 477 |
| MPL(5) | 482 |
| MPDB(5) | 487 |
| MPB(5) | 492 |
| MPDQ(5,10) | 497 |
| MPQ(5,10) | 547 |
| MPP(5,5) | 597 |
| MPDP(5,5) | 622 |

STDCM(882)

| | | |
|-------------|--------------------------------|-----|
| DERIV(7,21) | | 1 |
| DRV1(7,21) | (both rotors for flutter case) | 148 |
| DRV2(7,21) | | 295 |
| DRVWB(7,21) | | 442 |
| DRVHT(7,21) | | 589 |
| DRVVT(7,21) | | 736 |

variables (21):

$$\begin{aligned} & (\ddot{z}_F \quad \dot{\phi}_F \quad \dot{\theta}_F \quad \dot{\psi}_F \quad \dot{x}_F \quad \dot{y}_F \quad \dot{z}_F \quad \dot{\psi}_S \\ & \theta_0 \quad \theta_{1c} \quad \theta_{1s} \quad \theta_0 \quad \theta_{1c} \quad \theta_{1s} \quad \delta_f \quad \delta_e \quad \delta_a \quad \delta_r \\ & u_G \quad v_G \quad w_G) \end{aligned}$$

equations (7):

$$(L \quad M \quad N \quad X \quad Y \quad Z \quad Q)$$

STMCM(340)

| | |
|------------|-----|
| A2FD(7,7) | 1 |
| A1FD(7,7) | 50 |
| AOFD(7,7) | 99 |
| BFD(7,19) | 148 |
| DOFFD(7) | 281 |
| CONFD(16) | 288 |
| GUSFD(3) | 304 |
| DOF1FD(7) | 307 |
| NAMXFD(7) | 314 |
| NAMVFD(19) | 321 |
| MXFD | 340 |

variables (7):

$(\phi_F \ \theta_F \ \psi_F \ x_F \ y_F \ z_F \ \psi_S)$

controls (19):

$(\theta_0 \ \theta_{1c} \ \theta_{1s} \ \theta_0 \ \theta_{1c} \ \theta_{1s} \ \delta_f \ \delta_e \ \delta_a \ \delta_r \ \theta_t \ \delta_0 \ \delta_c \ \delta_s \ \delta_p \ \delta_t \ u_G \ v_G \ w_G)$

gust components in wind axes

TRANCM(62)

| | | |
|-------------|---|----|
| QTRIM(6) | trim generalized force (total) | 1 |
| CQST1 | trim $-\delta 2C_Q / \omega_a$ (rotor #1) | 7 |
| CQST2 | trim $-\delta 2C_Q / \omega_a$ (rotor #2) | 8 |
| IBODYI(7,7) | inverse of body inertia | 9 |
| DCSAS | SAS δ_c | 58 |
| DSSAS | SAS δ_s | 59 |
| TTGOV | transient governor $\Delta \theta_t$ | 60 |
| T1GOV | transient governor ($\Delta \theta_{govr}$) rotor#1 | 61 |
| T2GOV | transient governor ($\Delta \theta_{govr}$) rotor#2 | 62 |

2. SUBPROGRAM FUNCTION AND COMMUNICATION

This section describes the functions of the subprograms that constitute the computer program. The communication of the subprograms with each other is also described, in terms of the input and output variables. The description begins with the subprogram name, and its arguments. Next there is a statement of the principal function of the subprogram, and usually a general reference to a section in the analysis development. Then notes about the program content are given, including references to sections in the analysis development as appropriate. Finally all the input and output variables of the subprogram are listed. The left-hand column gives the variable name in the subprogram, and the right-hand column gives the label of the common block in which the variable is located. Some description of the variable may be given as well. Only the subprograms for rotor #1 are described; the subprograms for rotor #2 have identical functions and structure.

MAIN

Name: MAIN

Function: primary job and analysis control

General reference: section 5.3.5

CPRTR2

TRIMCM

IDENT(4)

ANTYPE(3)

TMDATA

FILEID(4)

RESTRT

CASECM

JCASE

TASK

JOB

RSWRT

NCASES

BLKDAT

RDFILE

START

TIMER

Name: TIMER(N,I,T)

Function: program timer

N integer parameter controlling timing calculations
 0 initialize
 1 start timer
 2 stop timer
 3 print times
 other return present time

I timer number
 1 case
 2 TRIM
 3 FLUT
 4 STAB
 5 TRAN
 6 STABL
 7 FLUTL
 8 WAKEC1,WAKEC2
 9 GEOMR1,GEOMR2
 10 RAMF
 11 MODE1,MODE2
 12 MOTNR1,MOTNR2
 13 PERF
 14 LOAD

T elapsed CPU time (sec)

DEBUG integer parameter: print time T if GE 1

TMDATA

ITDB

IDB(23)

INPTN

Name: INPTN

Function: input for new job

| | | |
|------------|--|--------|
| JCASE | | CASECM |
| BLKDAT | | |
| RDFILE | | |
| DEBUGI | integer parameter: debug print control | TMDATA |
| OPREAD(10) | | |
| NROTOR | | |
| IXX | | BDDATA |
| IYY | | |
| IZZ | | |
| IXY | | |
| IXZ | | |
| IYZ | | |
| ATILT | | |
| FSCG | | |
| BLCG | | |
| WLCG | | |
| WEIGHT | | |
| FILEID(4) | | TMDATA |
| : | | |
| : | | |
| MHARMF | | |

INPTO

Name: INPTO

Function: input for old job

RESTRT

CASECM

DEBUGI integer parameter: debug print control

TMDATA

NROTOR

ANTYPE(3)

OPREAD(10)

DEBUG(25)

NPRNTI

INPTA1

Name: INPTA1

Function: read airfoil table file

DEBUG

TMDATA

TITLE(20)

A1TABL

IDENT(4)

NMAX

NAB

NA(20)

A(20)

NMB

NM(20)

M(20)

NRB

R(11)

CLT(5000)

CDT(5000)

CMT(5000)

INPTR1

Name: INPTR1

Function: read rotor annelist

DEBUG

TMDATA

TITLE(20)

R1DATA

⋮

TWISTI(51)

INPTW1

Name: INPTW1

Function: read wake namelist

DEBUG

TMDATA

FACTWU

W1DATA

:

KWGSO(4)

KFWG

G1DATA

:

DQWG(2)

INPTB

Name: INPTB

Function: read body namelist

DEBUG

TMDATA

TITLE(20)

BDDATA

·

DOFSYM(10)

LFTAW

BADATA

·

OPTINT

ENGPOS

ENDATA

·

KEDAMP

INPTL1

Name: INPTL1

Function: read loads namelist

DEBUG

TMDATA

MHARML

L1DATA

:

OPNOIS(4)

MVIB

LADATA

:

ZETAV(3,10,10)

INPTF

Name: INPTF

Function: read flutter namelist for new job

DEBUG

TMDATA

OPFLOW

FLDATA

:

NAMEXR(3)

INPTS

Name: INPTS

Function: read flight dynamics namelist for new job

DEBUG

TMDATA

NPRNTP

STDATA

:

DOFPLT(21)

OPTRAN

GCDATA

:

CMAG(5)

INPTT

Name: INPTT

Function: read transient namelist for new job

DEBUG

TMDATA

NPRNTT

TNDATA

:

OPLMDA

OPTRAN

GCDATA

:

CMAG(5)

INPTG

Name: INPTG

Function: read flutter namelist for old job

DEBUG

ANTYPE(4)

:

NAMEXR(3)

TMDATA

FLDATA

INPTU

Name: INPTU

Function: read flight dynamics namelist for old job

DEBUG

TMDATA

OPPRNT(4)

STDATA

:

DOFPLT(21)

OPTRAN

GCDATA

:

CMAG(5)

INPTV

Name: INPTV

Function: read transient namelist for old job

DEBUG

TMDATA

NPRNTT

TNDATA

NPRNTP

NPRNTL

NRSTRT

TMAX

FILEI

Name: FILEI(NFILE,RDWRIT)

Function: read or write input file

NFILE file unit number

RDWRIT integer parameter: 0 to read file, 1 to write file

TITLBD(20)

BDDATA

TITLR1(20)

R1DATA

TITLR2(20)

R2DATA

TITLCS(20)

TMDATA

FILEID(4)

all

TMDATA

all

BDDATA

all

BADATA

all

ENDATA

all

LADATA

all

GCDATA

all

TNDATA

all

STDATA

all

FLDATA

all

R1DATA

all

W1DATA

all

G1DATA

all

L1DATA

all

R2DATA

all

W2DATA

all

G2DATA

all

L2DATA

FILEJ

Name: FILEJ(NFILE,RDWR)

Function: read or write trim data file

NFILE file unit number

RDWR integer parameter: 0 to read file, 1 to write file

| | |
|--------|--------|
| MPSI | TMDATA |
| LEVEL1 | |
| LEVEL2 | |
| KNW1 | W1DATA |
| MRG1 | |
| MRL1 | |
| KFWG1 | G1DATA |
| KNW2 | W2DATA |
| MRG2 | |
| MRL2 | |
| KFWG2 | G2DATA |
| all | TRIMCM |
| all | BODYCM |
| all | ENGNCM |
| all | GUSTCM |
| all | CONTCM |
| all | CONVCM |
| all | MNSCM |
| all | QBDCM |
| all | RTR1CM |
| all | RH1CM |
| all | MD1CM |
| all | INC1CM |
| all | WKV1CM |
| all | MNH1CM |
| all | AES1CM |
| all | MNR1CM |
| all | AEF1CM |
| all | QR1CM |
| all | RTR2CM |
| all | RH2CM |
| all | MD2CM |
| all | INC2CM |
| all | WKV2CM |
| all | MNH2CM |
| all | AES2CM |
| all | MNR2CM |
| all | AEF2CM |
| all | QR2CM |

FILER

Name: FILER(RDWRT)

Function: read or write restart file

Restart file structure:

- 1) case header record
- 2) input, trim, airfoil data
- 3) task header record -- ID,NREC
(ID = 2 for flutter, 3 for flight
dynamics, 4 for transient)
- 4) task data (NREC records)
- 5) repeat #3 and #4 as necessary
- 6) end record -- ID = 0, NREC = 0

RDWRT integer parameter: 0 to read file, 1 to write file

RESTRT

CASECM

TITLCS(20)

TMDATA

FILEID(4)

NROTOR

CODE

IDENT(4)

TRIMCM

TITLR1(20)

R1DATA

TITLR2(20)

R2DATA

TITLBD(20)

BDDATA

TITLA1(20)

A1TABL

AF1ID(4)

NMAX1

CLT1(5000)

CDT1(5000)

CMT1(5000)

TITLA2(20)

A2TABL

AF2ID(4)

NMAX2

CLT2(5000)

CDT2(5000)

CMT2(5000)

FILEF

Name: FILEF(RDWRT)

Function: read or write flutter restart file

RDWRT integer parameter: 0 to read file, 1 to write file

NROTOR

TMDATA

OPFDAN

FLDATA

NBM1

RTR1CM

NTM1

NGM1

NBM2

RTR2CM

NTM2

NGM2

all

FLMCM

all

STDCM

all

STMCM

all

MD1CM

all

MD2CM

all

STDATA

all

GCDATA

FILES

Name: FILES(RDWRT)

Function: read or write flight dynamics restart file

RDWRT integer parameter: 0 to read file, 1 to write file

all
all
all
all

STDCM
STMCM
STDATA
GCDATA

FILET

Name: FILET(RDWRT,ENDREC)

Function: read or write transient restart file

RDWRT integer parameter: 0 to read file, 1 to write file
ENDREC integer parameter: 0 if at start of transient record,
 1 if at end of record (required for file write only)

IT
YN(7)
DYN(7)
DDYN(7)
MTRACE
TRACE(14377)

WORK

LEVEL1
LEVEL2

TMDATA

all
all
all
all
all
all

TRANCM
TNDATA
GC DATA
L1 DATA
L2 DATA
LADATA

FILEE

Name: FILEE(KEY)

Function: write eigenvalue file

| | | |
|-----|---------|---------------------------------|
| KEY | integer | parameter defining case |
| | 0 | start file |
| | | flutter, const. coeff. (FLUTL) |
| | 1 | complete |
| | 2 | symmetric |
| | 3 | antisymmetric |
| | | flutter, periodic coeff. (FLUT) |
| | 4 | complete |
| | 5 | symmetric |
| | 6 | antisymmetric |
| | | flight dynamics (STABL) |
| | 7-18 | 6+IEQ (IEQ = equation type) |

| | | |
|------------|-------------------------------------|--------|
| TASK | | CASECM |
| JCASE | | |
| IDENT(4) | | TRIMCM |
| CODE | | TMDATA |
| LAMDA(60) | λ (constant coefficients) | EIGVC |
| MX2 | | |
| LMDAP(60) | λ (periodic coefficients) | EIGVP |
| LMDACP(60) | λ_c (periodic coefficients) | |
| MX2P | | |

INIT

Name: INIT

Function: initialization

NRC TOR

TMDATA

INITA

Name: INITA

Function: initialize environment parameters

General reference: section 2.5

OPUNIT

TMDATA

ALTMSL

TEMP

DENSEI

OPDENS

DENSE

TRIMCM

ALTD

DRATIO

CSOUND

INITC

Name: INITC

Function: initialize case parameters

OPUNIT
DEBUG
MPSI
MHARM(2)
MHARMF(2)
OPTRIM
OPGOVT
LEVEL2
DOF(54)
DOFT(8)
VKTS
VEL
VTIP
RPM
COLL
LATCYC
LNGCYC
PEDAL
APITCH
AROLL
ACCLIMB
AYAW
RTURN
NROTOR
XTRIM
CXTRIM

THETFT
PHIFT
THETFP
PSIFP
THETAT
PSIT
DVBODY(6)
DOMEGA
DDZF
VPILOT(5)
TGOVR1
TGOVR2

NBLD1
VTIPN
RADIUS
SIGMA
GAMMAO

TMDATA

CONTCM

R1DATA

OMEGA1
OMEGA2
HMASS

TRATIO
CONFIG
WEIGHT

NBLD2

DRATIO
DENSE
GRAV
CXTARG
OPRTR2
DPSI
FSCALE
RSCALE
NSCALE
ISCALE
GSCALE
SSCALE
CSCALE
COSPSI(36)
SINPSI(36)
KEPSI(21,36)

INITC

RTR1CM
RTR2CM
BODYCM

BDDATA

R2DATA

TRJMCM

INITR1

Name: INITR1

Function: initialize rotor parameters

Normalization parameters: section 2.6

Aerodynamic r, Δr : section 2.4.1

Tip loss factor: section 2.4.5

Linear twist: section 2.3.5

Control system damping: section 5.1.3

Gimbal/teeter spring and damping: sections 2.2.12, 2.2.13

Lag damper: section 2.2.16

DEBUG

TMDATA

MPSI

DOF(16)

rotor degrees of freedom

DOFT(4)

LEVEL

TRATIO

BDDATA

DENSE

TRIMCM

CSOUND

DRATIO

QRTR(6)

QR1CM

FHUBM(6)

CLS

CXS

CTS

CYS

CPS

CT

CMX

CMY

BO

BC

BS

CIRC(36)

K2T

WG1CM

K2SI

K2SO

GAMMAO

R1DATA

SIGMA

NBLADE

RADIUS

VTIPN

TDAMPO

TDAMPC

TDAMPR

INITR1

R1DATA

NUGCO
NUGSO
GDAMPC
GDAMPS
LDAMPC
LDAMPM
LDAMPR
MRB
MRM
RAE(31)
MRA
BTIP
OPTIP
TWISTA(30)
TWISTI(51)
RI(51)
MRI
INFLOW(6)
LINTW
TWISTL

OMEGA
GLAG
MLD
DZLD
CGS
CGC
NUGC
NUGS
CTO
CTC
CTR
MTIP
GAMMA
CMEAN
IB
NBM
NTM
NGM
NBMT
RA(30)
DRA(30)
FTIP(30)

CTOLD
CMYOLD
CMYOLD
VIND(3,30,36)
LAMBDA

RTR1CM

WKV1CM

| | |
|----------------|--------|
| | INIR1 |
| VINT(3,30,36) | WKV1CM |
| VORH(3,36) | |
| LAMBDI | |
| VWB(3,36) | |
| VHT(3,36) | |
| VVT(3,36) | |
| VOFF(3,36) | |
| LAMBDW(3) | |
| LAMBDH(3) | |
| LAMBDV(3) | |
| LAMBD0(3) | |
| EINTW(3) | |
| EINTH(3) | |
| EINTV(3) | |
| STATE(30,36,3) | AES1CM |
| DCLMAX(30,36) | |
| DCIMAX(30,36) | |
| DCMMAX(30,36) | |
| ALPHA(30,36) | |
| BETA(21,10) | MNR1CM |
| THETA(21,5) | |
| BETAG(21) | |
| PHI(10,16) | |
| PSID(10,6) | |
| QSSTAT(10) | MNSCM |
| PISTAT | |
| PESTAT | |
| FORCE(16,36) | AEF1CM |
| FHUB(6,36) | |
| TORQUE(36) | |
| T75OLD | MD1CM |
| NBMOLD | |
| NTMOLD | |
| VGUST(3,30,36) | GUSTCM |
| VGUSTH(3) | |

INITB

Name: INITB

Function: initialize airframe parameters

Position of aircraft components: section 4.1.5

Rotation matrix R_{SF} : section 4.1.2

\vec{r} , R_{SF} without Θ_T/Ψ_T rotations: sections 4.1.3, 4.1.5

(for wind tunnel trim case)

Control matrix T_{CFE} : section 4.1.6

Aircraft inertia: section 4.2.4

Airframe elastic modes:

- a) pitch/mast-bending coupling (KMST): section 4.2.3
- b) mode shape at hub (AMODE): section 4.2.2
- c) mass, spring, damping: section 4.2.4
- d) aerodynamic damping and control: section 4.2.7

Initialization (for wind tunnel case)

$$R_{FV} = R_e = R_{FE} = I, \quad R_e^T I^* R_e = I^*$$

$$\vec{V} = V \vec{i}_F, \quad \vec{k}_E = \vec{i}_F$$

$$-M^* (\vec{V} \times) R_e = -M^* V (\vec{i}_F \times)$$

$$(\vec{V} \times) R_e \vec{k}_F = -V \vec{j}_F$$

$$G = -M^* g (\vec{k}_F \times)$$

DEBUG

TMDATA

VEL

DOF(16)

airframe degrees of freedom

GRAV

TRIMCM

GAMMA

reference rotor

SIGMA

IB

OMEGA

NBLADE

RADIUS

P21MR1

0.

RTR1CM

P21WR1

$\Delta\Psi_{21}$ (rad)

P21MR2

$\Delta\Psi_{21}$ (rad)

RTR2CM

P21WR2

$-\Delta\Psi_{21}$ (rad)

ROTAT1

R1DATA

OPHVB1(3)

| | | |
|--------------|-----------------------|--------|
| | | INITB |
| ROTAT2 | | R2DATA |
| OPHVB2(3) | | |
| VGWBV(3) | gust in velocity axes | GUSTCM |
| VGHTV(3) | | |
| VGVTV(3) | | |
| QWB(6) | | QBDCM |
| QHT(6) | | |
| QVT(6) | | |
| AMODE1(6,10) | | BODYCM |
| : | | |
| : | | |
| VSIDE | | |
| TITLE(20) | | BDDATA |
| : | | |
| : | | |
| DOFSYM(10) | | |
| DRGIW | | BADATA |

INITE

Name: INITE

Function: initialize drive train parameters

Engine inertia and control: sections 4.3.1, 4.3.2

Governor parameters (dimensionless): section 4.3.3

Drive train spring constants: section 4.3.2

| | | |
|--------|--------------------------------|--------|
| DEBUG | | TMDATA |
| OPENG | | |
| DOF(6) | drive train degrees of freedom | |
| TRATIO | | BDDATA |
| NBLADE | reference rotor | TRIMCM |
| IB | | |
| OMEGA | | |
| ENGPCS | | ENDATA |
| THRTL | | |
| IENG | | |
| KMAST1 | | |
| KMAST2 | | |
| KICS | | |
| KENG | | |
| KPE | | |
| KP1 | | |
| KP2 | | |
| T1E | | |
| T11 | | |
| T12 | | |
| T2E | | |
| T21 | | |
| T22 | | |
| QTHRTL | | ENGNCM |
| IENG | | |
| KMI1 | | |
| KMI2 | | |
| KMR | | |
| KME1 | | |
| KME2 | | |
| KPGOVE | | |
| KPGOV1 | | |
| KPGOV2 | | |
| T1GOVE | | |
| T1GOV1 | | |
| T1GOV2 | | |
| T2GOVE | | |
| T2GOV1 | | |
| T2GOV2 | | |
| NDM | | |

CHEKR1

Name: CHEKR1

Function: check for fatal errors

| | | |
|-----------|-------------|--------|
| MPSI | | TMDATA |
| LEVEL | | |
| NBLADE | | R1DATA |
| MRA | | |
| RAE(31) | | |
| MRI | | |
| RI(51) | | |
| RROOT | | |
| INFLOW(6) | | |
| MRG | | W1DATA |
| NG(30) | | |
| MRL | | |
| NL(30) | | |
| KNW | | |
| RA(30) | | RTR1CM |
| MRLO | other rotor | R2DATA |

PRNTJ

Name: PRNTJ

Function: print job input data

FILEID(4)

all

all

TMDATA

CASECM

UNITNO

PRNTC

Name: PRNTC

Function: print case input data

| | |
|------------|--------|
| JCASE | CASECM |
| JOB | |
| START | |
| FILEID(4) | TMDATA |
| TITLCS(20) | |
| CODE | |
| ANTYPE(3) | |
| CPUNIT | |
| CPTRIM | |
| NROTOR | |
| VKTS | |
| VEL | |
| RPM | |
| VTIP | |
| ALTMSL | |
| TEMP | |
| CPGRND | |
| HAGL | |
| AFLAP | |
| CPENGN | |
| CPGCVT | |
| RTURN | |
| LEVEL1 | |
| LEVEL2 | |
| DOF(54) | |
| DOFT(8) | |
| MPSI | |
| MHARM | |
| MHARMF | |
| OPDENS | |
| IDENT(4) | TRIMCM |
| DENSE | |
| DRATIO | |
| CSOUND | |
| ALTD | |
| TITLBD(20) | BDDATA |
| WEIGHT | |
| FSCG | |
| WLCG | |
| BLCG | |
| CONFIG | |
| ATILT | |

| | |
|------------|--------|
| CWS | PRNTC |
| NAM | BODYCM |
| NDM | ENGNCM |
| TITLA1(20) | A1TABL |
| AF1ID(4) | |
| TITLA2(20) | A2TABL |
| AF2ID(4) | |
| TITLR1(20) | R1DATA |
| TYPE1 | |
| RADUS1 | |
| NBLD1 | |
| SIGMA1 | |
| INFLW1(6) | |
| OPHVB1(3) | |
| OPSTL1 | |
| OPYAW1 | |
| OPCMP1 | |
| OPUSL1 | |
| ROTAT1 | |
| HINGE1 | |
| ELAG1 | |
| EFLAP1 | |
| GAMMA1 | RTR1CM |
| OMEGA1 | |
| MTIP1 | |
| CMEAN1 | |
| IB1 | |
| NBM1 | |
| NTM1 | |
| NGM1 | |
| NBMT1 | |
| TITLR2(20) | R2DATA |
| : | |
| : | |
| EFLAP2 | |
| GAMMA2 | RTR2CM |
| : | |
| : | |
| NBMT2 | |

PRNT

Name: PRNT

Function: print trim input data

FILEID(4)

:

MHARMF(2)

TMDATA

PRNTR1

Name: PRNTR1

Function: print rotor input data

NBM

RTR1CM

NTM

NGM

RA(30)

DRA(30)

FTIP(30)

TITLE(20)

R1DATA

:

:

TWISTI(51)

PRNTW1

Name: PRNTW1

Function: print wake input data

| | |
|----------|--------|
| MPSI | TMDATA |
| LEVEL | |
| FACTOR | W1DATA |
| : | |
| : | |
| KWGSO(4) | |
| KFWG | G1DATA |
| : | |
| : | |
| DQWG(2) | |

PRNTB

Name: PRNTB

Function: print body input data

NROTOR

TMDATA

TITLE(20)

BDDATA

:

DOFSYM(10)

LFTAW

BADATA

:

OPTINT

ENGPOS

ENDATA

:

KEDAMP

PRNTF

Name: PRNTF

Function: print flutter input data

IDENT(4)

CONFIG

CPFLOW

:

CPUSLD

TRIMCM

BDDATA

FLDATA

PRNTS

Name: PRNTS

Function: print flight dynamics input data

IDENT(4)

TRIMCM

NPRNTP

STDATA

:

GUS(3)

PRNTT

Name: PRNTT

Function: print transient input data

IDENT(4)

TRIMCM

NPRNTT

TNDATA

:

QPLMDA

PRNTG

Name: PRNTG

Function: print transient gust and control input data

NROTOR

TMDATA

OPTRAN

GCDATA

:

CMAG(5)

TRIM

Name: TRIM

Function: trim

General reference: sections 5.3.5, 5.3.1

RESTR1

RSWRT

OPRTR2

LEVEL1

LEVEL2

ITERU

ITERR

ITERF

NPRNTT

NPRNTP

NPRNTL

CASECM

TRINCM

TMDATA

TRIMI

Name: TRIMI(LEVEL1,LEVEL2)

Function: calculate trim solution by iteration

General reference: section 5.3.1

Codes:

control number (C) = 1 2 3 4 5 6 7 8 9
control = δ_0 δ_c δ_s δ_p θ_{FT} ϕ_{FT} ψ_{FP} θ_{FP} θ_T

test number (T) = 1 2 3 4 5 6 7 8 9 10 11
test = none \vec{F} \vec{M} $F_x F_z$ M_y C_P C_T β_c β_s $C_L C_X$ $C_L C_X C_Y$

| OPTRIM | MT | C(i) | T(i) | (i = 1 to MT) |
|--------|----|---------------|---------------|---------------|
| 0 | 0 | | | |
| 1 | 6 | 1 2 3 4 5 6 | 2 1 1 3 1 1 | |
| 2 | 6 | 1 2 3 4 5 7 | 2 1 1 3 1 1 | |
| 3 | 7 | 1 2 3 4 5 6 8 | 2 1 1 3 1 1 6 | |
| 4 | 7 | 1 2 3 4 5 7 8 | 2 1 1 3 1 1 6 | |
| 5 | 3 | 1 3 5 | 4 1 5 | |
| 6 | 4 | 1 3 5 8 | 4 1 5 6 | |
| 7 | 0 | | | |
| 8 | 0 | | | |
| 9 | 0 | | | |
| 10 | 0 | | | |
| 11 | 1 | 1 | 7 | |
| 12 | 1 | 9 | 7 | |
| 13 | 1 | 1 | 6 | |
| 14 | 2 | 2 3 | 8 9 | |
| 15 | 3 | 1 2 3 | 7 8 9 | |
| 16 | 3 | 1 2 3 | 11 1 1 | |
| 17 | 3 | 1 2 9 | 11 1 1 | |
| 18 | 4 | 1 2 3 9 | 10 1 8 9 | |
| 19 | 3 | 1 2 3 | 11 1 1 | |
| 20 | 3 | 1 2 9 | 11 1 1 | |
| 21 | 4 | 1 2 3 9 | 10 1 8 9 | |
| 22 | 1 | 3 | 8 | |
| 23 | 2 | 1 3 | 7 8 | |
| 24 | 2 | 1 3 | 10 1 | |
| 25 | 2 | 1 9 | 10 1 | |
| 26 | 3 | 1 3 9 | 10 1 8 | |
| 27 | 2 | 1 3 | 10 1 | |
| 28 | 2 | 1 9 | 10 1 | |
| 29 | 3 | 1 3 9 | 10 1 8 | |

| | | |
|------------|--|--------|
| | | TRIMI |
| LEVEL1 | wake analysis for rotor #1 and rotor #2: | |
| LEVEL2 | 0 for uniform inflow, 1 for prescribed | |
| | wake, 2 for free wake | |
| DEBUG | | TMDATA |
| CPTRIM | | |
| CTTRIM | | |
| CYTRIM | | |
| BSTRIM | | |
| BCTRIM | | |
| OPTRIM | | |
| MTRIM | | |
| MTRIMD | | |
| FACTOR | | |
| ITERM | | |
| ITERC | | |
| DELTA | | |
| EPTRIM | | |
| OPGOVT | | |
| CXTARG | | TRIMCM |
| GRAV | | |
| COUNTT | | |
| CNTRLZ(11) | | BDDATA |
| CWS | | BODYCM |
| KE(3) | | |
| VXREKF(3) | | |
| TCFE(11,5) | | |
| COUNTM | | CONVCM |
| COUNTC | | |
| NBLD1 | | R1DATA |
| ROTATE | | |
| NBLD2 | | R2DATA |
| GAMMA1 | | RTR1CM |
| OMEGA1 | | |
| IB1 | | |
| GAMMA2 | | RTR2CM |
| OMEGA2 | | |
| IB2 | | |
| VCNTRL(11) | | CONTCM |
| THETFT | | |
| PHIFT | | |
| THETFP | | |
| PSIFP | | |
| THETAT | | |
| DPSIF | $\dot{\psi}_f$ | |
| VPILOT(5) | | |
| TGOVR1 | | |
| TGOVR2 | | |

QRTR1(6)

CLS

CXS

CTS

CYS

CPS

BETAC

BETAS

CQS1

$$C_Q/\sigma = C_P/\sigma$$

QRTR2(6)

CQS2

$$C_Q/\sigma = C_P/\sigma$$

QWB(6)

QHT(6)

QVT(6)

TRIMI

QR1CM

QR2CM

QBDCM

TRIMP

Name: TRIMP(LEVEL1,LEVEL2,ITER,ITERM)

Function: print trim solution

LEVEL1 wake analysis for rotor #1 and rotor #2:
LEVEL2 0 for uniform inflow, 1 for prescribed
 wake, 2 for free wake

ITER iteration number

ITERM maximum number of iterations

| | |
|-----------|--------|
| CPTRIM | TMDATA |
| CTTRIM | |
| CYTRIM | |
| BCTRIM | |
| BSTRIM | |
| OPTRIM | |
| MTRIM | |
| EPTRIM | |
| CPGOVT | |
| COLL | |
| LATCYC | |
| LNGCYC | |
| PEDAL | |
| APITCH | |
| AYAW | |
| AROLL | |
| ACLIMB | |
| CXTARG | TRIMCM |
| GRAV | |
| COUNTT | |
| OPRTR2 | |
| NBLD1 | R1DATA |
| TYPE1 | |
| NBLD2 | R2DATA |
| TYPE2 | |
| GAMMA1 | RTR1CM |
| OMEGA1 | |
| IB1 | |
| GAMMA2 | RTR2CM |
| OMEGA2 | |
| IB2 | |
| CWS | BODYCM |
| KE(3) | |
| VXREKF(3) | |

| | | |
|------------|---------------------------|--------|
| VCNTRL(11) | | TRIMP |
| THETFT | | CONTCM |
| PHIFT | | |
| THETFP | | |
| PSIFP | | |
| THETAT | | |
| PSIT | | |
| DPSIF | $\frac{1}{4}F$ | |
| VPILOT(5) | | |
| TGOVR1 | | |
| TGOVR2 | | |
| QRTR1(6) | | QR1CM |
| CLS | | |
| CXS | | |
| CTS | | |
| CYS | | |
| CPS | | |
| BETAC | | |
| BETAS | | |
| CQS1 | $C_Q/\sigma = C_P/\sigma$ | |
| QRTR2(6) | | QR2CM |
| CQS2 | $C_Q/\sigma = C_P/\sigma$ | |
| QWB(6) | | QBDCM |
| QHT(6) | | |
| QVT(6) | | |

FLUT

Name: FLUT

Function: flutter

General reference: sections 5.3.5, 5.3.6

RSWRT
RESTRT

CASECM

OPRTR2
NBLADE

TRIMCM

OPFLOW
CPSYMM
OPFDAN
MPSIPC
NINTPC
NBLDFL

FLDATA

A2(6400)

FLMCM

⋮

MGA

MXFD

STMCM

FLUTM

Name: FLUTM(PSI)

Function: calculate flutter matrices

General reference: section 6.3.1

Inflow dynamics: sections 6.1.5, 2.4.3

$$DLDT = \frac{\tau_a}{2\gamma} \frac{\partial \lambda}{\partial \tau}$$

$$DLDM = \frac{\tau_a}{2\gamma} \frac{\partial \lambda}{\partial m}$$

$$TT = \tau_\tau$$

$$TM = \tau_m$$

$$DL DZ = \frac{\partial \lambda}{\partial z}$$

$$ZK = \vec{V}_E \cdot \vec{z}_k$$

Drive train equations: section 6.2.3

Construct flight dynamics matrices: section 5.3.3 also
(only if rigid body degrees of freedom present)

Symmetric/antisymmetric matrices: section 6.3.3

PSI Ψ (for periodic coefficients)

DEBUG

TMDATA

OPENGN

OPRTR2

TRIMCM

DOFSYM(10)

BDDATA

TRATIO

CONFIG

NEM

REULER(3,3)

BODYCM

KE(3)

RHUB1(3)

RHUB2(3)

AMODE1(6,10)

AMODE2(6,10)

KMSTC1(10)

KMSTS1(10)

KMSTC2(10)

KMSTS2(10)

MVXRE(3,3)

TCFE(11,5)

KIGOVE

ENDATA

KIGOV1

KIGOV2

| | |
|--------------|--------|
| | FLUTM |
| GSE | ENDATA |
| GSI | |
| QTHRTL | ENGNCM |
| IENG | |
| QEDAMP | |
| KMI1 | |
| KMI2 | |
| KMR | |
| KME1 | |
| KME2 | |
| KPGOVE | |
| KPGOV1 | |
| KPGOV2 | |
| T1GOVE | |
| T1GOV1 | |
| T1GOV2 | |
| T2GOVE | |
| T2GOV1 | |
| T2GOV2 | |
| MENG22 | |
| MENG33 | |
| SENG22 | |
| SENG33 | |
| RADUS1 | R1DATA |
| NBLD1 | |
| KFLMD1 | |
| KHLMD1 | |
| SIGMA1 | |
| FXLMD1 | |
| FYLMD1 | |
| KINTH1 | |
| KINTF1 | |
| FMLMD1 | |
| OMEGA1 | RTR1CM |
| NTM1 | |
| NBM1 | |
| NGM1 | |
| MUX1 | |
| MUY1 | |
| MUZ1 | |
| GAMMA1 | |
| IB1 | |
| RGUST1(3,3) | |
| CHUB1(6,16) | |
| CBHUB1(3,3) | |
| CHUBT1(16,6) | |

| | | |
|--------------|--------------------------|--------|
| | | FLUTM |
| RADUS2 | | R2DATA |
| : | | |
| : | | |
| FMLMD2 | | |
| OMEGA2 | | RTR2CM |
| : | | |
| : | | |
| CHUBT2(16,6) | | |
| KPB1(10) | | MD1CM |
| KPG1 | | |
| KPB2(10) | | MD2CM |
| KPG2 | | |
| T1C1 | | CONTCM |
| T1S1 | | |
| T1C2 | | |
| T1S2 | | |
| LAMBD1 | | WKV1CM |
| COSE1 | | |
| ZAGL1 | | |
| LAMBD2 | | WKV2CM |
| COSE2 | | |
| LAMBD2 | | |
| CTS1 | $\delta 2C_T / \sigma_a$ | QR1CM |
| CTS2 | $\delta 2C_T / \sigma_a$ | QR2CM |
| DERIV(7,21) | | STDCM |
| DRVR1(7,21) | | |
| DRVWB(7,21) | | |
| DRVHT(7,21) | | |
| DRVVT(7,21) | | |
| A2FD(7,7) | | STMCM |
| : | | |
| : | | |
| MXFD | | |
| CPFLOW | | FLDATA |
| OPSYMM | | |
| NBLADE | | |
| OPSAS | | |
| KCSAS | | |
| KSSAS | | |
| TCSAS | | |
| TSSAS | | |
| OPTCRS(2) | | |
| CPGRND | | |
| KASGE | | |

| | |
|-------------|--------|
| DOF(80) | FLUTM |
| CON(26) | FLDATA |
| GUS(3) | |
| A2(6400) | FLMCM |
| : | |
| MGA | |
| A2A(16,16) | FLMACM |
| : | |
| BLA(16,2) | |
| A2R1(30,30) | FLM1CM |
| : | |
| DGR1(6,3) | |
| A2R2(30,30) | FLM2CM |
| : | |
| DGR2(6,3) | |

FLUTB

Name: FLUTB

Function: calculate flutter aircraft matrices

General reference: section 6.2.2

| | | |
|--------------|---|--------|
| OPRTR2 | | TRIMCM |
| NEM | | BDDATA |
| IBODY(3,3) | | BODYCM |
| MSTAR | | |
| MVXRE(3,3) | | |
| GMTRX(3,3) | | |
| RFV(3,3) | | |
| AMASS(10) | | |
| ADAMPS(10) | | |
| ASPRNG(10) | | |
| ADAMPA(10) | | |
| ACNTRL(4,10) | | |
| DELTA | | FLDATA |
| OPRINT | | |
| DVBODY(6) | | CONTCM |
| DDZF | | |
| CNTRL(4) | $(\delta_f \delta_e \delta_a \delta_r)$ | |
| GWB(3) | gust in F axes | GUSTCM |
| GHT(3) | | |
| GVT(3) | | |
| QWB(6) | | QBDCM |
| QHT(6) | | |
| QVT(6) | | |
| A2(16,16) | | FLMACM |
| : | | |
| BL(16,2) | | |
| DRVWB(7,21) | | STDGM |
| DRVHT(7,21) | | |
| DRVVT(7,21) | | |
| LMDAW1(3) | | WKV1CM |
| LMDAH1(3) | | |
| LMDAV1(3) | | |
| EINTW1(3) | | |
| EINTH1(3) | | |
| EINTV1(3) | | |
| LMDAW2(3) | | WKV2CM |
| : | | |
| EINTV2(3) | | |

FLUTR1

Name: FLUTR1(PSI)

Function: calculate flutter rotor matrices

General reference: sections 6.1.6, 6.4

Azimuthal summations:

$$\begin{array}{lll} \frac{1}{J} \sum_{m=1}^Z M_{m,1} & \text{at } \psi_m = \psi + m \frac{2\pi}{Z} & \text{for periodic coefficients} \\ \frac{1}{J} \sum_{j=1}^J M_{j,1} & \text{at } \psi_j = j \frac{2\pi}{J} & \text{for constant coefficient} \\ & & \text{approximation} \\ & & \text{(section 6.1.7)} \end{array}$$

Reorder hub reactions: \sum_u equation multiplied by 2 to get $(-\delta 2C_T / \sigma a)$

Inflow dynamics due to velocity perturbations: sections 6.1.4, 6.1.6

PSI ψ (periodic coefficients only)

CPFLOW
MPSICC
NBLDFL

FLDATA

KBM
KTM
NGM
GAMMA
NUGC
NUGS
CGC
CGS
CTO
CTC
CTR
MUX
MUY
MUZ

RTR1CM

NBLD
GSB(10)
GST(5)
KHLMDA
KFLMDA

R1DATA

NU(10)
WT(5)
WTO
WTC
WTR
KPB(10)
KPG

MD1CM

LAMBDA
 CTS $\gamma 2C_T / \sqrt{a}$
 T1C
 T1S
 A2(30,30)
 :
 DG(6,3)
 MASSB
 :
 SPQ(5,10)
 MQU(10)
 :
 MPDP(5,5)

FLUTR1
 WKV1CM
 QR1CM
 CONTCM
 FLM1CM
 FLINCM
 FLAECM

FLUTII1

Name: FLUTII1(Psi)

Function: calculate flutter inertia coefficients

General reference: section 6.1.3

PSI

Ψ

DEBUG
DOFT(4)

TMDATA

GLAG
KBM
KTM
NBMT

RTR1CM

BETA(21,10)

MNR1CM

ETAPH(2,10)

MD1CM

MB

INC1CM

:

SPQT(5,10,4)

MASSBL

FLINCM

:

SPQL(5,10)

FLUTA1

Name: FLUTA1(PSI)

Function: calculate flutter aerodynamic coefficients

General reference: section 6.1.4

Perturbation section forces: without c/c_m factor

Aerodynamic coefficients: $FZ0 = C_T/\sigma$, $FX0 = C_Q/\sigma$

PSI ψ

DEBUG

TMDATA

DOFT(4)

MPSI

TRIMCM

DPSI

R1DATA

MRA

CHORD(30)

XA(30)

XAC(30)

CPCOMP

OPYAW

CPSTLL

RFA

RA(30)

RTR1CM

DRA(30)

CMEAN

FTIP(30)

NBMT

KBM

KTM

MTIP

MUX

MUY

MUZ

ETA(2,10,30)

bending modes at r_i , $i = 1$ to MRA

MD1CM

ETAP(2,10,30)

ETAPP(2,10,30)

ZETA(5,30)

torsion modes at r_i , $i = 1$ to MRA

ZETAP(5,30)

DEL1

DEL2

DEL3

DEL4

DEL5

DALPHA

FLDATA

DMACH

OPUSLD

BETA(21,10)
DCLDS(30,36)
DCDLS(30,36)
DCMDS(30,36)
SAVE(30,36,19)
XAPQ(2,5,4,30)
MQU(10)
:
MPDP(5,5)

FLUTA1

MNR1CM

AES1CM

INC1CM

FLAECM

FLUTL

Name: FLUTL(ID,A2,A1,A0,B,MX,MX1,MV,MG,DOF1,NAMEX,NAMEV)

Function: analyze flutter constant coefficient linear equations

Vibration point location: sections 4.1.3, 4.1.5

| | | |
|-----------|--|--------|
| ID | problem identification: 1 for complete dynamics, 2 for symmetric, 3 for antisymmetric | |
| A2(MX*MX) | coefficient matrices | |
| A1(MX*MX) | | |
| A0(MX*MX) | | |
| B(MX*MV) | control matrix | |
| MX | number of degrees of freedom | |
| MX1 | number of first order degrees of freedom | |
| MV | number of controls | |
| MG | number of gust components | |
| DOF1(MX) | integer vector designating first order degrees of freedom | |
| NAMEX(MX) | vector of variable names | |
| NAMEV(MV) | vector of control names | |
| VELF(3) | | BODYCM |
| GRAV | | TRIMCM |
| OMEGA | reference rotor | |
| RADIUS | reference rotor | |
| FSCG | | BDDATA |
| BLCG | | |
| WLCG | | |
| NEM | | |
| THETFT | | CONTCM |
| PHIFT | | |
| THETAT | | |
| PSIT | | |
| ANTYPE(4) | | FLDATA |
| : | | |
| NAMEXR(3) | | |

STAB

Name: STAB

Function: flight dynamics

General reference: sections 5.3.5, 5.3.3

RESTR

CASECM

RSWRT

STABM

Name: STABM

Function: calculate flight dynamics stability derivatives and matrices

General reference: section 5.3.3

Print during stability derivative calculations:

- a) increment: 1st number dimensionless, 2nd number dimensional
- b) motion and controls: 1st number dimensionless, 2nd number dimensional
 - 1) angular velocity = deg/sec
 - 2) linear velocity, gust velocity = ft/sec or m/sec
 - 3) $\dot{\Psi}_s$ = rpm
 - 4) \ddot{z}_F = ft/sec² or m/sec²
 - 5) controls = deg
- c) generalized forces: moments and forces in $\delta C/\delta a$ form (rotor #1 parameters, body axes); torque in $-\delta C_Q/\delta a$ form (rotor #1 parameters)

| | |
|--------------|--------|
| MPSI | TMDATA |
| LEVEL1 | |
| LEVEL2 | |
| DEBUG | |
| OPRTR2 | TRIMCM |
| LSCALE | |
| FSCALE | |
| NBLD1 | R1DATA |
| MRA1 | |
| TYPE1 | |
| IB1 | RTR1CM |
| CHUB1(6,16) | |
| CHUBT1(16,6) | |
| OMEGA1 | |
| NBLD2 | R2DATA |
| MRA2 | |
| TYPE2 | |
| IB2 | RTR2CM |
| CHUB2(6,16) | |
| CHUBT2(16,6) | |
| OMEGA2 | |
| IBODY(3,3) | BODYCM |
| MSTAR | |
| MVXRE(3,3) | |
| GMTRX(3,3) | |
| TCFE(11,5) | |

| | | |
|-----------------|-----------------------------|--------|
| CONFIG | | STABM |
| QRTR1(6) | | BDDATA |
| CQS1 | - γ 2C $\frac{Q}{a}$ | QR1CM |
| QRTR2(6) | | QR2CM |
| CQS2 | - γ 2C $\frac{Q}{a}$ | |
| I01 | | INC1CM |
| I02 | | INC2CM |
| IRSTAR | | ENGNCM |
| QTHRTL | | |
| QEDAMP | | |
| KPGOVE | | |
| KPGOV1 | | |
| KPGOV2 | | |
| KIGOVE | | ENDATA |
| KIGOV1 | | |
| KIGOV2 | | |
| NPRNTP | | STDATA |
| NPRNTL | | |
| ITERS | | |
| OPLMDA | | |
| DELTA | | |
| DOF(7) | | |
| CON(16) | | |
| GUS(3) | | |
| VGWBV(3) | | GUSTCM |
| VGHTV(3) | | |
| VGVTV(3) | | |
| VGRTR1(3,30,36) | | |
| VGRTR2(3,30,36) | | |
| VGHUB1(3) | | |
| VGHUB2(3) | | |
| VCTRL(11) | | CONTCM |
| INBODY(6) | | |
| ICOMEGA | | |
| DOZF | | |
| QWB(6) | | QBDCM |
| QHT(6) | | |
| QVT(6) | | |
| DERIV(7,21) | | STDCM |
| : | | |
| : | | |
| DRVVT(7,21) | | |
| A2FD(7,7) | | STMCM |
| : | | |
| WYFD | | |

STABD

Name: STABD

Function: print stability derivatives

General reference: section 5.3.3

Options: a) rotor coefficient form, $M^*X = \gamma 2C/\sigma a$
b) stability derivative form, X (acceleration)
c) dimensionless or dimensional

Dimensions:

a) force or moment

| | forces (FF) | moments (FM) | torque (FQ) |
|-------------|------------------------------|----------------------------|-----------------|
| M^*X form | $\frac{1}{2}Nl_b \Omega^2/R$ | $\frac{1}{2}Nl_b \Omega^2$ | $Nl_b \Omega^2$ |
| X form | $\Omega^2 R$ | Ω^2 | Ω^2 |

b) subscripts

acceleration (\ddot{z}) = $\Omega^2 R$ (FA)

angular velocity = Ω

linear velocity = ΩR (FV)

controls = 57.3

gust velocity = ΩR (FV)

TASK

CASECM

DOFFD(7)

STMCM

CONF(16)

GUSFD(3)

NAMEV(19)

ISTAR(3,3)

BODYCM

MSTAR

IRSTAR

ENGNCM

NBLADE

reference rotor

TRIMCM

IB

OMEGA

RADIUS

OPRNT(4)

STDATA

DRVR1(7,21)

STDCM

DRVR2(7,21)

DRVWB(7,21)

DRVHT(7,21)

DRVVT(7,21)

STABE

Name: STABE

Function: calculate flight dynamics equations

| | | |
|------------|-----------------|--------|
| DEBUG | | TMDATA |
| OMEGA | reference rotor | TRIMCM |
| EQTYPE(12) | | STDATA |
| KCSAS | | |
| KSSAS | | |
| TCSAS | | |
| TSSAS | | |
| A2FD(49) | | STMCM |
| : | | |
| MXFD | | |
| OPSYMM | | FLDATA |
| OPSASF | | |
| TASK | | CASECM |

STABL

Name: STABL(IEQ,A2,A1,A0,B,MX,MX1,MV,MG,DOF1,NAMEX,NAMEV,DOF,CON)

Function: analyze flight dynamics linear equations

Vibration point location: sections 4.1.3, 4.1.5

Numerical integration of transient: sections 5.3.2, 5.3.3
(see also program TRAN)

| | | |
|------------|---|--------|
| IEQ | equation type identifier | |
| A2(MX*MX) | coefficient matrices | |
| A1(MX*MX) | | |
| A0(MX*MX) | | |
| B(MX*MV) | control matrix | |
| MX | number of degrees of freedom | |
| MX1 | number of first order degrees of freedom | |
| MV | number of controls | |
| MG | number of gust components | |
| DOF1(MX) | integer vector designating first order degrees of freedom | |
| NAMEX(MX) | vector of variable names | |
| NAMEV(MV) | vector of control names | |
| DOF(7) | integer vector designating degrees of freedom used | |
| CON(19) | integer vector designating controls used | |
| OMEGA | reference rotor | TRIMCM |
| RADIUS | | |
| GRAV | | |
| VELF(3) | | BODYCM |
| VGHUB1(3) | | GUSTCM |
| VPTRAN(5) | | |
| FSCG | | BDDATA |
| WLCG | | |
| BLCG | | |
| THETFT | | CONTCM |
| PHIFT | | |
| THETAT | | |
| PSIT | | |
| DVBODY(6) | | |
| DOMEGA | | |
| NPRNTT | | STDATA |
| : | | |
| DOFPLT(21) | | |

STABP

Name: STABP(TIM,IT,YN,DYN,DDYN,DOF)

Function: print flight dynamics transient solution

General reference: section 5.3.3

Print during numerical integration (in STABL):

- a) controls in deg
- b) gust velocity: 1st number dimensionless, 2nd number dimensional
- c) aircraft motion: 1st number dimensionless, 2nd number dimensional
 - 1) displacement = deg, ft or m
 - 2) velocity = deg/sec, ft/sec or m/sec
 - 3) acceleration = deg/sec², g
 - 4) inertial axes = deg/sec, g

$$AANG = \vec{\omega} = R_e \begin{pmatrix} \dot{\phi}_F \\ \dot{\theta}_F \\ \dot{\psi}_F \end{pmatrix}$$

$$ALIN = \vec{a}_{body} = \begin{pmatrix} \ddot{x}_F \\ \ddot{y}_F \\ \ddot{z}_F \end{pmatrix} - (\vec{V} \times) R_e \begin{pmatrix} \dot{\phi}_F \\ \dot{\theta}_F \\ \dot{\psi}_F \end{pmatrix}$$

| | |
|---------|--|
| TIM | time (dimensionless) |
| IT | time count |
| YN(7) | $(\phi_F \ \theta_F \ \psi_F \ x_F \ y_F \ z_F \ \psi_s)$ |
| DYN(7) | $(\dot{\phi}_F \ \dot{\theta}_F \ \dot{\psi}_F \ \dot{x}_F \ \dot{y}_F \ \dot{z}_F \ \dot{\psi}_s)$ |
| DDYN(7) | $(\ddot{\phi}_F \ \ddot{\theta}_F \ \ddot{\psi}_F \ \ddot{x}_F \ \ddot{y}_F \ \ddot{z}_F \ \ddot{\psi}_s)$ |
| DOF(7) | integer vector: 0 if degree of freedom not used |

GRAV
LSCALE
FSCALE

TRIMCM

TSTEP
TMAX
NPRNTT

STDATA

VGHUB1(3)
VPTRAN(5)
MSTAR
MVXRE(3,3)
REULER(3,3)

STABP

GUSTCM

BODYCM

TRAN

Name: TRAN

Function: transient

General reference: sections 5.3.5, 5.3.2

| | | |
|--------------|---------------------------|--------|
| RESTRT | | CASECM |
| RSWRT | | |
| LEVEL1 | | TMDATA |
| LEVEL2 | | |
| DVBODY(6) | | CONTCM |
| DOMEGA | | |
| MVXRE(3,3) | | BODYCM |
| MSTAR | | |
| IBODY(3,3) | | |
| OMEGA | reference rotor | TRIMCM |
| QRTR1(6) | | QR1CM |
| CQS1 | $-\gamma_{2C_Q/\sigma_a}$ | |
| QRTR2(6) | | QR2CM |
| CQS2 | $-\gamma_{2C_Q/\sigma_a}$ | |
| QWB(6) | | QBDCM |
| QHT(6) | | |
| QVT(6) | | |
| QTRIM(6) | | TRANCM |
| CQST1 | | |
| CQST2 | | |
| IBODYI(7,7) | | |
| NPRNTT | | TNDATA |
| NPRNTP | | |
| NPRNTL | | |
| NRSTRT | | |
| TMAX | | |
| TSTEP | | |
| OPPLOT | | |
| DOFPLT(21) | | |
| DOF(7) | | |
| I01 | | INC1CM |
| I02 | | INC2CM |
| CHUB1(6,16) | | RTR1CM |
| CHUBT1(16,6) | | |
| OMEGA1 | | |
| IB1 | | |

CHUB2(6,16)
CHUBT2(16,6)
OMEGA2
IB2
NBLD1
NBLD2
IRSTAR

TRAN

RTR2CM

R1DATA

R2DATA

ENGNCM

DOF(7)
OPSAS
KCSAS
KSSAS
TCSAS
TSSAS
ITERT
OPLMDA

QTRIM(6)
CQST1
CQST2
IBODYI(7,7)
DCSAS
DSSAS
TTGOV
T1GOV
T2GOV

VPTRAN(5)
VCNTRL(11)
DVBODY(6)
DOMEGA
DDZF
VPILOT(5)
TGOVR1
TGOVR2

TRANI

TNDATA

TRANCM

GUSTCM

CONTCM

TRANP

Name: TRANP(TIM,IT,YN,DYN,DDYN)

Function: print transient solution

General reference: section 5.3.2

Print notes:

- a) controls in deg
- b) gust velocity dimensional
- c) aircraft motion: 1st number dimensionless, 2nd number dimensional
 - 1) displacement = deg, ft or m
 - 2) velocity = deg/sec, ft/sec or m/sec
 - 3) acceleration = deg/sec², g
 - 4) inertial axes = deg/sec, g
- d) generalized forces: moments and forces in $\delta 2C/\sigma$ a form (rotor #1 parameters, body axes); torque in $-\delta c_Q/\sigma$ a form (rotor #1 parameters)

$$AANG = \vec{\omega} = R_e \begin{pmatrix} \dot{\phi}_F \\ \dot{\theta}_F \\ \dot{\psi}_F \end{pmatrix}$$

$$ALIN = \vec{a}_{body} = \begin{pmatrix} \ddot{x}_F \\ \ddot{y}_F \\ \ddot{z}_F \end{pmatrix} - (\vec{V} \times) R_e \begin{pmatrix} \dot{\phi}_F \\ \dot{\theta}_F \\ \dot{\psi}_F \end{pmatrix}$$

TIM time (dimensionless)

IT time count

YN(?) ($\phi_F \ \theta_F \ \psi_F \ x_F \ y_F \ z_F \ \psi_S$)

DYN(?) ($\dot{\phi}_F \ \dot{\theta}_F \ \dot{\psi}_F \ \dot{x}_F \ \dot{y}_F \ \dot{z}_F \ \dot{\psi}_S$)

DDYN(?) ($\ddot{\phi}_F \ \ddot{\theta}_F \ \ddot{\psi}_F \ \ddot{x}_F \ \ddot{y}_F \ \ddot{z}_F \ \ddot{\psi}_S$)

LEVEL1

TMDATA

LEVEL2

FSCALE

TRIMCM

LSCALE

GRAV

OPRTR2

| | | |
|-------------|--------------------------|--------|
| ITERT | | TRANP |
| OPLMDA | | TNDATA |
| TSTEP | | |
| TMAX | | |
| MSTAR | | BODYCM |
| REULER(3,3) | | |
| MOVRE(3,3) | | |
| GMTRX(3,3) | | |
| QTHRTL | | ENGNCM |
| QEDAMP | | |
| VGWBV(3) | | GUSTCM |
| VGHTV(3) | | |
| VGVTV(3) | | |
| VGHUB1(3) | | |
| VGHUB2(3) | | |
| VPIRAN(5) | | |
| NBLD1 | | R1DATA |
| TYPE1 | | |
| IB1 | | RTR1CM |
| OMEGA1 | | |
| NBLD2 | | R2DATA |
| TYPE2 | | |
| IB2 | | RTR2CM |
| OMEGA2 | | |
| QRTR1(6) | | QR1CM |
| CQS1 | $-\gamma \frac{2C_Q}{a}$ | |
| QRTR2(6) | | QR2CM |
| CQS2 | $-\gamma \frac{2C_Q}{a}$ | |
| QWB(6) | | |
| QHT(6) | | |
| QVT(6) | | |
| VCNTRL(11) | | CONTCM |
| VPILOT(5) | | |
| TGOVR1 | | |
| TGOVR2 | | |
| QTRIM(6) | | TRANCM |
| CQST1 | | |
| CQST2 | | |
| DCSAS | | |
| DSSAS | | |
| TTGOV | | |
| T1GOV | | |
| T2GOV | | |

TRANC

Name: TRANC(TIM)

Function: calculate transient gust and control

General reference: section 5.3.4

| | | |
|-----------------|----------------------|--------|
| TIM | time (dimensionless) | |
| VELF | $V/\Omega R$ | TMDATA |
| MPSI | | |
| OMEGA | reference rotor | TRIMCM |
| RADIUS | | |
| COSPSI(36) | | |
| SINPSI(36) | | |
| OPRTR2 | | |
| RA1(30) | | RTR1CM |
| RA2(30) | | RTR2CM |
| RWB(3) | | BODYCM |
| RHT(3) | | |
| RVT(3) | | |
| RFV(3,3) | | |
| RSF1(3,3) | | |
| RSF2(3,3) | | |
| RHUB1(3) | | |
| RHUB2(3) | | |
| MRA1 | | R1DATA |
| ROTAT1 | | |
| MRA2 | | R2DATA |
| ROTAT2 | | |
| VGWBV(3) | gust in wind axes | GUSTCM |
| VGHTV(3) | | |
| VGVT(3) | | |
| VGRTR1(3,30,36) | | |
| VGRTR2(3,30,36) | | |
| VGHUB1(3) | | |
| VGHUB2(3) | | |
| VPTRAN(5) | | |
| OPTRAN | | GCDATA |
| : | | |
| : | | |
| CMAG(5) | | |

CONTRL

Name: CONTRL(T,PERIOD,C)

Function: calculate transient control time history

General reference: section 5.3.4

Calculates: $C(t) = \frac{1}{2}(1 - \cos 2\pi t/T)$

T time(sec)

PERIOD period T (sec)

C control C

GUSTU

Name: GUSTU(T,PERIOD,G)

Function: calculate uniform gust time history

General reference: section 5.3.4

Calculates: $G(t) = \frac{1}{2}(1 - \cos 2\pi t/T)$

T time (sec)

PERIOD period T (sec)

G gust G

GUSTC

Name: GUSTC(XG,L,L0,G)

Function: calculate convected gust wave shape

General reference: section 5.3.4

Calculates: $G(x_g) = \frac{1}{2}(1 - \cos 2\pi(x_g - L_0)/L)$

XG distance x_g (ft or m)

L wavelength L (ft or m)

L0 starting position L_0 (ft or m)

G gust G

PERF

Name: PERF

Function: Performance

General reference: section 5.2.1

Operating condition:

a) motion: 1st number dimensionless, 2nd number dimensional

- 1) velocity = ft/sec or m/sec
- 2) dynamic pressure, $q = \text{lb/ft}^2$ or N/m^2
- 3) weight, $C_W/\sqrt{} = \text{lb}$ or N
- 4) body motion = deg/sec, ft/sec or m/sec
- 5) $\ddot{z} = \text{ft/sec}^2$ or m/sec^2
- 6) $\Psi_s = \text{rpm}$

b) body orientation and controls in deg

Circulation convergence:

- a) tolerance, CG/S in $C_T/\sqrt{}$ form
- b) $G/E = \text{ratio error to tolerance} (\leq 1 \text{ if converged})$

Motion convergence:

- a) tolerance, BETA (etc) in deg
- b) $\text{BETA}/E \text{ (etc)} = \text{ratio error to tolerance} (\leq 1 \text{ if converged})$

Airframe performance: section 4.2.6

- a) aerodynamic loads: dimensional
- b) components:
 - 1) angles in deg
 - 2) loads, q dimensional
 - 3) induced velocity, total velocity dimensionless

Gust velocity: dimensionless

System power: dimensional (HP); number in parentheses is percent total power

- a) climb power = $V_c W$

System efficiency parameters:

- a) gross weight, $W = \text{lb}$ or N
- b) drag-rotor = $D_r = (P_1 + P_o)/V$; $D/q\text{-rotor} = D_r/\frac{1}{2} \rho V^2$;
 $L/D\text{-rotor} = W/D_r$
- c) drag-total = $D_{\text{total}} = P_{\text{total}}/V$; $D/q\text{-total} = D_{\text{total}}/\frac{1}{2} \rho V^2$;
 $L/D\text{-total} = W/D_{\text{total}}$
- d) figure of merit = $M = 1 - P_{\text{nonideal}}/P_{\text{total}}$

| | | |
|------------|-------------------|--------|
| | | PERF |
| VEL | | TMDATA |
| ITERM | | |
| EPMOTN | | |
| ITERC | | |
| EPCIRC | | |
| AFLAP | | |
| OPRTR2 | | TRIMCM |
| GRAV | | |
| SIGMA | | |
| RADIUS | | |
| OMEGA | | |
| DENSE | | |
| VELF(3) | | BODYCM |
| VCLIMB | | |
| VSIDE | | |
| CWS | | |
| HMASS | | |
| NAM | | |
| NDM | | ENGNCM |
| NBM1 | | RTR1CM |
| NTM1 | | |
| NGM1 | | |
| NBM2 | | RTR2CM |
| NTM2 | | |
| NGM2 | | |
| VGWB(3) | gust in wind axes | GUSTCM |
| VGHT(3) | | |
| VGVT(3) | | |
| VGHUB1(3) | | |
| VGHUB2(3) | | |
| VCNTRL(11) | | CONTCM |
| THETFT | | |
| PHIFT | | |
| THETFP | | |
| PSIFP | | |
| THETAT | | |
| PSIT | | |
| DVBODY(6) | | |
| DOMEGA | | |
| DDZF | | |
| SAVE(31) | | QBDCM |

LMDAW1(3}
LMDAH1(3}
LMDAV1(3}
LMDAW2(3}
LMDAH2(3}
LMDAV2(3}

B1MS(10)

⋮

COUNTC

PERF

WKV1CM

WKV2CM

CONVCM

PERFR1

Name: PERFR1(P,PCPP,PI,PINT,PO,PN)

Function: calculate and print rotor performance

General reference: section 5.2.1

Operating condition:

$$\begin{pmatrix} -\mu_x \\ \mu_y \\ \mu_z \end{pmatrix}_{\text{TPP}} = \begin{bmatrix} 1 & 0 & \beta_c \\ 0 & 1 & \beta_s \\ -\beta_c & -\beta_s & 1 \end{bmatrix} \begin{pmatrix} -\mu_x \\ \mu_y \\ \mu_z \end{pmatrix}_{\text{HP}}$$

$$\alpha_{\text{HP}} = \alpha_{\text{CP}} + \Theta_{1s} = \alpha_{\text{TPP}} - \beta_c$$

$$(\beta_c)_{\text{CP}} = (\beta_c + \Theta_{1s})_{\text{HP}}$$

$$(\beta_s)_{\text{CP}} = (\beta_s - \Theta_{1c})_{\text{HP}}$$

Harmonics of gimbal motion: section 5.1.2

Rotor forces and motion:

shaft axes (-S), tip path plane axes (-T), wind axes (L or X)
coefficient (Cx-), coefficient/solidity (Cx6-), dimensional (x-)

Rotor power: $L_{\text{IDEAL}} = \lambda_{\text{ideal}}$ (see also section 2.4.3)

| | |
|------|--------------------------|
| P | total power |
| PCPP | climb and parasite power |
| PI | induced power |
| PINT | interference power |
| PO | profile power |
| PN | non-ideal power |

| | | |
|--------------|----------|--------|
| OPUNIT | | TMDATA |
| VEL | | |
| MPSI | | |
| MHARM | | |
| MHARMF | | |
| DENSE | | TRIMCM |
| NAM | | BODYCM |
| NIM | | ENGNCM |
| T75 | | CONTCM |
| T1C | | |
| T1S | | |
| FZ(30,36) | F_z/ac | AES1CM |
| ALPHA(30,36) | | |

| | | |
|---------------|---------------------------------------|--------|
| VIND(3,30,36) | | PERFR1 |
| LAMBDA | | WKV1CM |
| VINT(3,30,36) | \nearrow_{int} (due to other rotor) | WKV2CM |
| LAMBDI | | R1DATA |
| RADIUS | | |
| SIGMA | | |
| MRA | | |
| TYPE | | |
| NBLADE | | |
| HINGE | | |
| MUX | | RTR1CM |
| MUY | | |
| MUZ | | |
| OMEGA | | |
| DRA(30) | | |
| RA(30) | | |
| ALFHP | | |
| PSIHP | | |
| MTIP | | |
| MAT | | |
| NBM | | |
| NTM | | |
| NGM | | |
| NUGC | | |
| NUGS | | |
| T75OLD | | MD1CM |
| NU(20) | | |
| ETA(2,10) | bending mode at tip | |
| WT(11) | | |
| WTO | | |
| WTC | | |
| WTR | | |
| FHUB(6) | | QR1CM |
| CLS | | |
| CXS | | |
| BETA0 | | |
| BETAC | | |
| BETAS | | |
| CIRC(36) | | |
| BETA(21,10) | | MNR1CM |
| THETA(21,5) | | |
| BETAG(21) | | |
| PHI(10,16) | | |
| PSID(10,6) | | |
| QSSTAT(10) | | MNSCM |
| PISTAT | | |
| PESTAT | | |

LOAD

Name: LOAD(LEVEL1,LEVEL2)

Function: loads, vibration, and noise

Airframe vibration: section 5.2.8

Vibration point location: sections 4.1.3, 4.1.5

LEVEL1 wake analysis level for rotor #1
LEVEL2 wake analysis level for rotor #2

MHARMF(2)

OPRTR2

FSCALE

LSCALE

GRAV

TRATIO

FSCG

WLCG

BLCG

NBLD1

OMEGA1

NBLD2

OMEGA2

MOVXRE(3,3)

MSTAR

REULER(3,3)

VELF(3)

NAM

THETAT

PSIT

PHI1(10,16)

PHI2(10,16)

MVIB

FSVIB(10)

WLVIB(10)

BLVIB(10)

ZETA(3,10,10)

TMDATA

TRIMCM

BDDATA

R1DATA

RTR1CM

R2DATA

RTR2CM

BODYCM

CONTGM

MNR1CM

MNR2CM

LADATA

LOADR1

Name: LOADR1(LEVEL)

Function: calculate and print rotor loads

Print aerodynamics (function r and Ψ):

- a) dimensionless quantities generally, angles in deg
- b) induced velocity in nonrotating shaft axes
- c) interference induced velocity is that due to other rotor
- d) gust components in velocity axes

Force/ c_{mean} (dimensionless):

$$L/C = \frac{1}{2}U^2(c/c_{\text{mean}})c_l = L/c_{\text{mean}}$$

$$D/C = \frac{1}{2}U^2(c/c_{\text{mean}})c_d = D/c_{\text{mean}}$$

$$M/C = \frac{1}{2}U^2(c^2/c_{\text{mean}})c_m = M/c_{\text{mean}}$$

$$DR/C = \frac{1}{2}U^2(c/c_{\text{mean}})c_{d\text{radial}} = D_{\text{radial}}/c_{\text{mean}}$$

$$FZ/C = CT/S = F_z/c_{\text{mean}} = d(C_T/\sigma)/dr$$

$$FX/C = F_x/c_{\text{mean}}$$

$$MA/C = M_a/c_{\text{mean}}$$

$$FR/C = F_r/c_{\text{mean}}$$

$$FRT/C = \tilde{F}_r/c_{\text{mean}}$$

Forces (dimensional)

| | | |
|-----|------------------------|-------------------|
| L | = section lift | lb/ft or N/m |
| D | = section drag | lb/ft or N/m |
| M | = section pitch moment | ft-lb/ft or m-N/m |
| DR | = section radial drag | lb/ft or N/m |
| FZ | = $F_z = dT/dr$ | lb/ft or N/m |
| FX | = F_x | lb/ft or N/m |
| MA | = M_a | ft-lb/ft or m-N/m |
| FR | = F_r | lb/ft or N/m |
| FRT | = \tilde{F}_r | lb/ft or N/m |

Blade section power: section 5.2.1

$$CP/S = d(C_P/\sigma)/dr$$

P = section power

HP/ft or HP/m

LEVEL level of wake analysis

OPUNIT

MPSI

TMDATA

| | | |
|----------------|--|--------|
| DENSE | | LOADR1 |
| DPSI | | TRIMCM |
| COSPSI(36) | | |
| SINPSI(36) | | |
| TYPE | | R1DATA |
| RADIUS | | |
| NBLADE | | |
| OPSTLL | | |
| CHORD(30) | | |
| INFLOW(6) | | |
| MRA | | |
| OMEGA | | RTR1CM |
| CMEAN | | |
| RA(30) | | |
| MUX | | |
| MUY | | |
| MUZ | | |
| NBM | | |
| NTM | | |
| NGM | | |
| PINTER(36) | | |
| PBURST(36) | | |
| ETAT(2,10) | bending mode at tip | MD1CM |
| ETA(2,10,30) | bending mode at r_i , $i = 1$ to MRA | |
| DBV | | W1DATA |
| VGUST(3,30,36) | | GUSTCM |
| GAM(30,36) | | QR1CM |
| CIRC(36) | | |
| MHLOAD | | L1DATA |
| MALOAD | | |
| MRLOAD | | |
| RLOAD(20) | | |
| NPOLAR | | |
| MWKGMP | | |
| MNOISE | | |
| RANGE(10) | | |
| ELVATN(10) | | |
| AZMUTH(10) | | |
| NPLOT(75) | | |
| SAVEM(36,78) | | LDMNCM |
| MOTION(78) | | AEMNCM |

LOADR1

AES1CM

STATE(30,36,3)
DCLMAX(30,36)
DCIMAX(30,36)
DCMMAX(30,36)
MEFF(30,36,3)
AEFF(30,36,3)
DCLDS(30,36)
DCIDS(30,36)
DCMDS(30,36)
SAVE(30,36,19)

WKV1CM

VIND(3,30,36)
LAMBDA
VWB(3,36)
VHT(3,36)
VVT(3,36)
VOFF(3,36)
LAMBDAW(3)
LAMBDAH(3)
LAMBDAV(3)
LAMBDO(3)
VORH(3,36)

WKV2CM

VINT(3,30,36)
LAMBDI

LOADH1

Name: LOADH1

Function: calculate and print hub and control loads

Root loads: MCON = $C_{m_{con}}/\sigma$ FHUBX = C_{f_x}/σ
 MHUBX = C_{m_x}/σ FHUBY = C_{f_y}/σ
 MHUBZ = C_{m_z}/σ FHUBZ = C_{f_z}/σ
 CENT = $C_{f_{cent}}/\sigma$

Hub loads: FHUBH = C_H/σ FHUBMX = C_{M_x}/σ
 FHUBY = C_Y/σ FHUBMY = C_{M_y}/σ
 FHUBT = C_T/σ FHUBQ = C_Q/σ

Harmonic analysis: $F_n = \frac{1}{J} \sum_{j=1}^J F_j e^{-in\psi_j} K_n$

Dimensional loads:

root force = $\rho \Omega^2 R^4 (c/R)$
root moment = $\rho \Omega^2 R^5 (c/R)$
hub force = $N \rho \Omega^2 R^4 (c/R) = \rho (\Omega R)^2 \pi R^2 c$
hub moment = $N \rho \Omega^2 R^5 (c/R) = \rho (\Omega R)^2 \pi R^3 c$

| | | |
|------------|---------------------------|--------|
| MHARM | | TMDATA |
| MPSI | | |
| NBLADE | | R1DATA |
| RADIUS | | |
| TYPE | | |
| CMEAN | | RTR1CM |
| GAMMA | | |
| OMEGA | | |
| NBM | | |
| NTM | | |
| DENSE | | TRIMCM |
| DPSI | | |
| COSPSI(36) | | |
| SINPSI(36) | | |
| MHARML | | L1DATA |
| NPLOT(75) | | |
| SENDUR(12) | for hub and control loads | |
| CMAT(12) | | |
| EXMAT(12) | | |
| KFATIG | | |

| | | |
|--------------|----------------------|--------|
| MPAERO(36) | $(M_{p0}/ac)_{aero}$ | LOADH1 |
| CMXA(36) | | AEF1CM |
| CMZA(36) | | |
| CFXA(36) | | |
| CFZA(36) | | |
| CFRA(36) | | |
| SAVEM(36,78) | | LDMNCM |
| MB | | INC1CM |
| SB | | |
| IO | | |
| SQ(2,10) | | |
| IQA(2,10) | | |
| IFX0 | | |
| IMX0 | | |
| IP(5) | | |
| IPP(5,5) | | |
| IPO(5) | | |
| IQODQ(2,10) | summed over q_j | |
| ... | | |
| SPQ(5,10) | | |

| | | |
|---------------|---|--------|
| | | LOADS1 |
| MHARML | | L1DATA |
| SENDUR(6) | for section loads | |
| CMAT(6) | | |
| EXMAT(6) | | |
| KFATIG | | |
| NPLOT(75) | | |
| ETA(2,10,30) | bending modes at r_i , $i = 1$ to MRA | MD1CM |
| DEL1 | | |
| DEL2 | | |
| DEL3 | | |
| DEL4 | | |
| DEL5 | | |
| FXAERO(30,36) | F_x/ac | AES1CM |
| FZAERO(30,36) | F^x/ac | |
| MAAERO(30,36) | M^z/ac | |
| FRAERO(30,36) | \tilde{F}_a/ac | |
| BETA(21,10) | | MNR1CM |
| MB | | LDMNCM |
| : | | |
| : | | |
| IP0 | | |
| SAVEM(36,78) | | |

LOADI1

Name: LOADI1(R,Q,TR,ZR,EPR,ER)

Function: calculate inertia coefficients for section loads

General reference: sections 5.2.2, 5.2.3, 5.2.4

Blade pitch: section 2.3.5

$$CS = \cos \Theta, SN = \sin \Theta, TR = \Theta(r)$$

$$W = (z_o \vec{i} - x_o \vec{k}), WP = (z_o \vec{i} - x_o \vec{k})', WPP = (z_o \vec{i} - x_o \vec{k})''$$
$$WXI = (z_o \vec{i} - x_o \vec{k} - x_I \vec{k})$$

$$ZR = \xi_i(r), ER = \vec{\eta}_i(r), EPR = \vec{\eta}_i'(r)$$

$$WR = (z_o \vec{i} - x_o \vec{k})_{trim}, WPR = (z_o \vec{i} - x_o \vec{k})'_{trim}, \text{ at } r$$
$$WRXC = (z_o \vec{i} - x_o \vec{k} - x_C \vec{k}), \text{ at } r$$

$$EPXIO(NBM) = (\vec{\eta}' \cdot \vec{k} x_I) \text{ at } r=e$$

$$CE(NBM) = \int_0^r \vec{\eta}_i'' \cdot (z_o \vec{i} - x_o \vec{k} - x_I \vec{k}) d\eta$$

$$CMR(MRM+1) = \int_{\eta}^{\eta'} (\eta^* - r) m d\eta^*$$

$$WFA = (z_o \vec{i} - x_o \vec{k}), WPFA = (z_o \vec{i} - x_o \vec{k})' \text{ at } r_{FA}$$

$$X = \vec{X}_k(\eta), XR = \vec{X}_k(r)$$

R radial station r/R

Q(4) mean deflection q_j

TR pitch Θ_m at r

ZR(5) ξ_k at r

EPR(2,10) $\vec{\eta}_k'$ at r

ER(2,10) $\vec{\eta}_k$ at r

DEBUG

T75

EFLAP

ELAG

XFA

RFA

ZFA

RCPL

NOFB

MRM

TMDATA

CONTCM

R1DATA

LOADI1

RTR1CM

NBM

NTM

NGM

NBMT

MASS(51)

ITHETA(51)

XI(51)

TWIST(51)

ETA(2,10,51)

bending modes at $r=(j-1)\Delta r$, $j=1$ to $MRM+1$

MD1CM

ETAP(2,10,51)

ETAPP(2,10,51)

ZETA(5,51)

torsion modes at $r=(j-1)\Delta r$, $j=1$ to $MRM+1$

ETAPH(2,10)

EFA(2,10)

bending modes at $r = r_{FA}$

EFAP(2,10)

DEL1

DEL2

DEL3

DEL4

DEL5

MB

:

:

:

IP0

LDMNCM

LOADF

Name: LOADF(S,MPSI,K,SE,C,M,DAMAGE,SEQ)

Function: calculate fatigue damage

General reference: section 5.2.9

Input:

S(MPSI) vector of load S_j , $j = 1$ to MPSI; dimensional

MPSI number of azimuthal stations; maximum 36

K parameter K in fatigue damage calculation

SE endurance limit S_E (dimensional)

M material exponent

C material constant

$$\text{S-N curve approximated by } N = \frac{C}{(S/S_E - 1)^M}$$

Output:

DAMAGE damage fraction per rev (only calculated if $S_E > 0$, $C > 0$, and $M \neq 0$)

SEQ equivalent $\frac{1}{2}$ peak-to-peak load (only calculated if $M \neq 0$)

LOADM

Name: LOADM(F,MPSI,FMEAN,FHPP)

Function: calculate mean and half peak-to-peak

Input:

F(MPSI) load F_j , $j = 1$ to MPSI

MPSI number of azimuthal stations

Output:

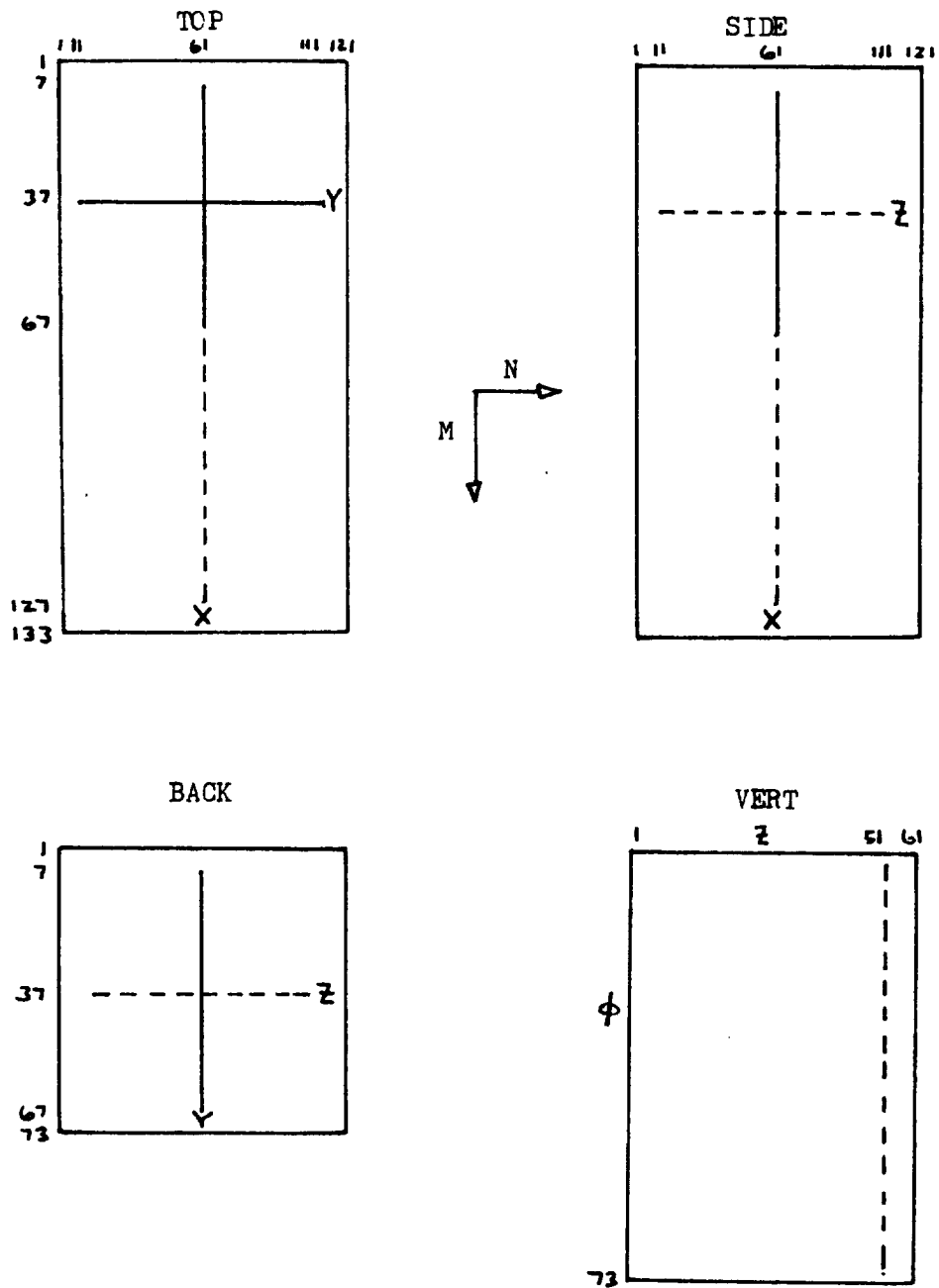
FMEAN mean load

FHPP $\frac{1}{2}$ peak-to-peak load

GEOMP1

Name: GEOMP1(LEVEL)

Function: printer-plot of wake geometry



GEOMP1

LEVEL

wake analysis: 1 for prescribed wake,
2 for free wake geometry

MPSI
TYPE

TMDATA
R1DATA
L1DATA

MWKGMP
JWKGMP(8)
NWKGMP(4)

KFW
KDW
KNW
KRW
KRWG
KFWG

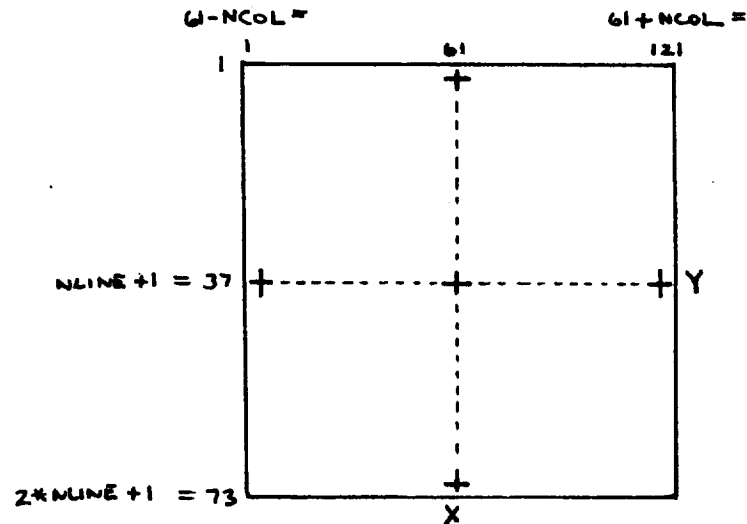
W1DATA

G1DATA

POLRPP

Name: POLRPP(A,MRA,RA,MPSI,ISUB,NPLOT,DA,NUPP)

Function: printer-plot of polar plot



| | |
|---------|---|
| A | array to be plotted |
| MRA | number of radial stations |
| RA(MRA) | radial stations r_i , $i = 1$ to MRA |
| MPSI | number of azimuthal stations $\psi_j = j \Delta\psi$, $j = 1$ to MPSI, $\Delta\psi = 360/\text{MPSI}$ |
| ISUB | first dimension of array A; positive if first subscript is r_i , negative if first subscript is ψ_j |
| NPLOT | n; data plotted every n-th step |
| DA | plot increment: last digit of integer part of A/DA is plotted (if multiple of NPLOT) |
| NUPP | unit number for printed output |

HISTPP

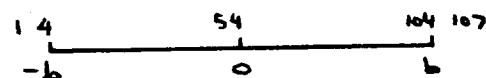
Name: HISTPP(A,MRA,RA,MPSI,ISUB,NPLOT,NAME,NUPP)

Function: printer-plot of azimuthal time history

let c = minimum, d = maximum values over azimuth

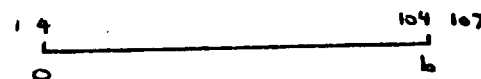
1) $d > 0, c < -.03d$ or $c < 0, d > .03|c|$

use $b = [\max(d, |c|)]$



2) $d > 2|c|, c > -.03d$

use $b = [d]$



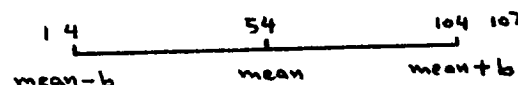
3) $c < -2|d|, d < .03c$

use $b = [|c|]$



4) otherwise, use $\text{mean} = [\frac{1}{2}(c+d)]$

and $b = [\max(\text{mean}-c, d-\text{mean})]$



$\text{mean} = \text{AM} = \text{KM} * 10^{**}\text{NM}$

$b = B = K * 10^{**}\text{N}$

to convert F to $K*10^N$ ($K = 1$ to 9)

a) if $F = 0$, then $F = .99$

b) $N = [\log |F|]$

if $F < 1.$, then $N = N - 1$

c) $K = [|F| / 10^{**}N] + 1$

if $K = 10$, then $N = N + 1$ and $K = 1$

if $F < 0$, then $K = -K$

d) $F = K * 10^{**}N$

HISTPP

A array to be plotted

MRA secondary variable: number of values (minimum 1)

RA(MRA) secondary variable: values r_i , $i = 1$ to MRA;
alphanumeric labels if NPLOT LT 0; not used if
MRA EQ 1

MPSI number of azimuthal stations $\Psi_j = j\Delta\Psi$, $j = 1$ to MPSI,
 $\Delta\Psi = 360/\text{MPSI}$

ISUB first dimension of array A; positive if first subscript
is r_i , negative if first subscript is Ψ_j

NPLOT number of values of secondary variable per plot;
minimum 1 and maximum 3; negative for alphanumeric
labels; not used if MRA EQ 1

NAME name of secondary variable, 4 characters; not used
if MRA EQ 1

NUPP unit number for printed output

NOISR1

Name: NOISR1(RANGE,ELVATN,AZMUTH)

Function: calculate and print far field rotational noise

General reference: section 5.2.10

Calculate constants: $CSTR = \cos \Theta_r / (1 - M_r)$

$$FT = -N^3 \Omega^2 / 4\pi \sigma_o (1 - M_r)^2$$
$$FD = N^2 / 4\pi \sigma_o (1 - M_r)$$
$$FL = -N^2 \Omega \sin \Theta_r / 4\pi c_s \sigma_o (1 - M_r)^2$$
$$FR = -N^2 \Omega \cos \Theta_r / 4\pi c_s \sigma_o (1 - M_r)^2$$
$$FB = N \Omega \cos \Theta_r / c_s (1 - M_r)$$
$$FS = N \Omega \sigma_o / c_s$$

Harmonic analysis of loads: $F_n = \frac{1}{J} \sum_{j=1}^J F_j e^{-in\psi_j} K_n$

RANGE range s_o (dimensional)
ELVATN elevation Θ_o (deg)
AZMUTH azimuth Ψ_o (deg)

MPSI
OPUNIT
DPSI
DENSE
CSOUND
COSPSI(36)
SINPSI(36)

TMDATA

TRIMCM

OMEGA
CMEAN
MUX
MUY
MUZ
RA(30)
DRA(30)
NBLADE
CHORD(30)
SIGMA
RADIUS
MRA
TYPE

RTR1CM

R1DATA

AXS(30)
OPNOIS(4)
MHARMN(3)
MTIMEN(3)

$$A_{xs}/c^2$$

L1DATA

FXA(30,36)
FZA(30,36)
FRA(30,36)

F_x/ac
F_x/ac
F_z/ac
F_r/ac

BETAC
BETAS

NCISR1

AES1CM

QR1CM

BESSEL

Name: BESSEL(NB,XB,BJ)

Function: calculate J Bessel function

Input:

| | |
|----|--------------------------------|
| NB | order of Bessel function, n |
| XB | argument of Bessel function, x |

Output:

| | |
|----|--------------------------|
| BJ | Bessel function $J_n(x)$ |
|----|--------------------------|

RAMF

Name: RAMF(LEVEL1,LEVEL2,OPLMDA)

Function: calculate rotor/airframe periodic motion and forces

General reference: section 5.1.13

Test motion convergence: section 5.1.4

Test circulation convergence: section 5.1.12

LEVEL1 integer parameter specifying rotor #1 and rotor #2

LEVEL2 wake analysis: 0 for uniform inflow, 1 or 2 for nonuniform inflow

OPLMDA integer parameter: 0 to suppress inflow update

MPSI

MHARM(2)

TMDATA

MHARMF(2)

ITERM

EPMCTN

ITERC

EPCIRC

DEBUG

MREV

MPSIR

OPRTR2

TRIMCM

NAM

BODYCM

NDM

ENGNCM

CMEAN1

RTR1CM

NBM1

NTM1

NGM1

CMEAN2

RTR2CM

NBM2

NTM2

NGM2

B1(21,10)

MNR1CM

T1(21,5)

BG1(21)

P1(10,16)

PS1(10,6)

B2(21,10)

MNR2CM

T2(21,5)

BG2(21)

P2(10,16)

PS2(10,6)

| | |
|-----------|--------|
| | RAMF |
| B1MS(10) | CONVCM |
| : | |
| COUNTC | |
| CIRC1(36) | QR1CM |
| CT1 | |
| CMX1 | |
| CMY1 | |
| CIRC2(36) | QR2CM |
| CT2 | |
| CMX2 | |
| CMY2 | |
| SIGMA1 | R1DATA |
| SIGMA2 | R2DATA |

MODE1

Name: MODE1

Function: blade modes

T75OLD
NBMOLD
NTMOLD

MD1CM

DEBUG
HINGE
EPMODE

TMDATA

R1DATA

NBM
NTM

RTR1CM

T75

CONTCM

MODEC1

Name: MODEC1

Function: initialize blade mode parameters

Linearly interpolate data for bending mode calculation: section 2.3.1

Tip mass: section 2.2.19

Evaluate centrifugal force for bending mode calculation: section 2.3.1

$$CENT = \int_0^1 \rho_m d\eta$$

Linearly interpolate data for torsion mode calculation: section 2.3.3

Evaluate pitch inertia and control system stiffness: sections 2.2.9, 5.1.3

MRB

R1DATA

MTIP

XITIP

EFLAP

ELAG

RFA

RADIUS

MRM

FTO

FTC

FTR

WTIN

VTIPN

KTOI

KTCI

KTRI

MRI

RI(51)

XI(51)

XC(51)

KP2(51)

MASS(51)

ITHETA(51)

GJ(51)

EIXX(51)

EIZZ(51)

TWIST(51)

DEBUG

TMDATA

MODEC1

RTR1CM

IB
OMEGA
EIXXB(51)
EIZZB(51)
MASSB(51)
TWISTB(51)
CENT(51)
ITHETB(51)
GJB(51)
MASSI(51)
ITHETI(51)
XII(51)
XCI(51)
TWISTI(51)
KP2I(51)
IPITCH
KTO
KTC
KTR

MODEB1

Name: MODEB1

Function: calculate blade bending modes

General reference: section 2.3.1

Blade pitch: section 2.3.5

Calculate:

$$\begin{aligned}DS &= \xi_k'(e) K_s / \Omega^2 R^3 \xi_i'(e) \\C &= \int_e \xi_k'' \cdot \xi_i'' dr \\DC &= \int_e \left[\int_r g m d\theta \xi_i' \cdot \xi_k' - m k_e \cdot \xi_k k_e \cdot \xi_i \right] dr \\B &= \int_e \xi_k \cdot \xi_i m dr \\A &= \int_e \xi_k'' (EI / \Omega^2 R^4)^{-1} \xi_i'' dr\end{aligned}$$

Normalize eigenvector solution: using Galerkin modes from last call,
which was at $r = 1$

T75
DEBUG

NOPB
RCPL
KFLAP
KLAG
EFLAP
ELAG
RADIUS
RCPLS
TSPRNG
RFA
RPB
NCOLB
MRB
NONROT
HINGE
MRA
RROOT
MRM

CONTCM
TM DATA
R1 DATA

NU(20)
NUNR(20)
ETA(2,10,96)
ETAP(2,10,96)
ETAPP(2,10,96)
ETAPH(2,10)

MD1CM

MODEB1

MASS(51)
EIXX(51)
EIZZ(51)
TWIST(51)
CENT(51)
OMEGA
NBM
RA(30)

inertial and structural data at
 $r = e + (j-1)\Delta r$, $r = 1$ to $MRB + 1$

RTR1CM

MODEG

Name: MODEG(R,EFLAP,ELAG,NCOLB,HINGE,F,DF,DDF)

Function: calculate Galerkin functions for bending modes

General reference: section 2.3.1

| | |
|------------|---|
| R | radial station r/R |
| EFLAP | flap hinge offset e_f/R |
| ELAG | lag hinge offset e_l/R |
| NCOLB | number of functions |
| HINGE | integer parameter: 0 for hinged blade, 1 for cantilever blade |
| F(NCOLB) | Galerkin functions f_i |
| DF(NCOLB) | Galerkin functions f'_i |
| DDF(NCOLB) | Galerkin functions f''_i |

MODEA1

Name: MODEA1

Function: calculate articulated blade flap and lag modes

General reference: section 2.3.2

Calculate: $F = \int_e^1 \eta m dr$, $G = \int_e^1 \eta^2 m dr$

DEBUG

TMDATA

MRB

R1DATA

EFLAP

ELAG

KFLAP

KLAG

RADIUS

MRM

RFA

RFB

MRA

RROOT

RA(30)

RTR1CM

OMEGA

NBM

MASS(51) section mass at $r = e + (j-1)\Delta r$, $j = 1$ to MRB+1

NU(20)

MD1CM

NUNR(20)

ETA(2,10,96)

ETAP(2,10,96)

ETAPP(2,10,96)

ETAPH(2,10)

MODET1

Name: MODET1

Function: calculate blade torsion modes

General reference: section 2.3.3

Evaluate Galerkin functions at r: $x = \pi(r - r_{FA})/(1 - r_{FA})$

Calculate:

$$A = \int_0^1 f_k' (GJ/\Omega^2 R^2)^{-1} f_i' dr$$

$$B = \int_0^1 I_0 f_k f_i dr$$

$$C = \int_0^1 f_k' f_i' dr$$

Normalize eigenvector solution: using Galerkin functions from last iteration, which was at $r = 1$

DEBUG

TMDATA

MRB

R1DATA

RFA

RADIUS

MRM

NCOLT

MRA

IPITCH

RTR1CM

KTO

KTC

KTR

OMETA

NTM

RA(30)

ITHETA(51)

GJ(51)

I_0 at $r = r_{FA} + (j-1)\Delta r$, $j = 1$ to MRB+1
 GJ at $r = r_{FA} + (j-1)\Delta r$, $j = 1$ to MRB+1

WT(11)

MD1CM

WTO

WTC

WTR

ZETA(5,92)

ZETAP(5,92)

MODEK1

Name: MODEK1

Function: calculate kinematic pitch-bending coupling

General reference: section 2.3.4

| | | |
|------------|---------------------------|--------|
| DEBUG | | TMDATA |
| T75 | | CONTCM |
| PHIPL | | R1DATA |
| PHIPH | | |
| RPH | | |
| RPB | | |
| XPH | | |
| KPIN | | |
| DEL3G | | |
| ATANKP(10) | | |
| ETA(2,10) | bending modes at r_{PB} | MD1CM |
| ETAP(2,10) | | |
| KPB(10) | | |
| KPG | | |
| NBM | | RTR1CM |

MODED1

Name: MODED1

Function: calculate blade root geometry

General reference: section 2.2.1

DEBUG

T75

CONE

DROOP

SWEEP

FIDROOP

FSWEEP

DEL1

DEL2

DEL3

DEL4

DEL5

TMDATA
CONTCM

R1DATA

MD1CM

INRTC1

Name: INRTC1

Function: calculate blade inertia coefficients

General reference: section 2.2.19

Blade pitch: section 2.3.5

Calculate: $CS(MRM+1) = \cos \Theta$, $SN(MRM+1) = \sin \Theta$

$$CM(MRM+1) = \int_r^1 m \, d\varrho$$

$$CMR(MRM+1) = \int_r^1 \varrho m \, d\varrho$$

$$CMRR(MRM+1) = \int_r^1 \varrho^2 m \, d\varrho$$

$$CXIM(MRM+1) = \int_r^1 x_I \cos \Theta m \, d\varrho$$

$$CXIRM(MRM+1) = \int_r^1 x_I \sin \Theta \varrho m \, d\varrho$$

$$DEM(NBM,MRM+1) = \int_r^1 \vec{k}_0 \cdot \vec{\gamma}_i m \, d\varrho$$

$$DERM(NBM,MRM+1) = \int_r^1 \vec{k}_0 \cdot \vec{\gamma}_i \varrho m \, d\varrho$$

$$CEPEP(NBM,NBMT,MRM+1) = \int_0^r \vec{\gamma}_i' \cdot \vec{\gamma}_j' \, d\varrho$$

$$X(2,NTM,NBMT,MRM+1) = \vec{x}_{kj}$$

$$a) \quad X = \int_{r_{FA}}^r \xi_k' (\vec{\gamma}_j - \varrho \vec{\gamma}_j') \, d\varrho$$

$$b) \quad XH = \int_{r_{FA}}^r \xi_k' \vec{\gamma}_j' \, d\varrho$$

$$c) \quad X = \vec{x}_{kj} \text{ for } k \geq 1 \text{ and } k = 0$$

$$XCFA = x_C \text{ at } r_{FA}$$

$$XCE = x_C \text{ at } e$$

$$XIE = x_I \text{ at } e$$

$$KP2TWP = k_P^2 \Theta_{tw}'$$

DEBUG
T75

MRM
NOPB
RCPL
RFA
ZFA
XFA
ELAG

TMDATA
CONTCM
R1DATA

| | | |
|----------------|---|--------|
| | | INRTC1 |
| RADIUS | | R1DATA |
| MBLADE | | |
| MRA | | |
| EFLAP | | |
| IB | | RTR1CM |
| NBM | | |
| NTM | | |
| NGM | | |
| NBMT | | |
| RA(30) | | |
| IPITCH | | |
| MASS(51) | inertial data at $r = (j-1)\Delta r$, $j = 1$ to $MRM+1$ | |
| ITHETA(51) | | |
| XI(51) | | |
| XC(51) | | |
| KP2(51) | | |
| TWIST(51) | | |
| ETA(2,10,51) | bending modes at $r = (j-1)\Delta r$, $j = 1$ to $MRM+1$ | |
| ETAP(2,10,51) | | |
| ETAPP(2,10,51) | | |
| ZETA(5,51) | torsion modes at $r = (j-1)\Delta r$, $j = 1$ to $MRM+1$ | |
| ZETAP(5,51) | | |
| EFA(2,10) | | |
| EFAP(2,10) | bending modes at r_{FA} | |
| ETAPH(2,10) | | |
| DEL1 | | |
| DEL2 | | |
| DEL3 | | |
| DEL4 | | |
| DEL5 | | |
| MB | | INC1CM |
| : | | |
| : | | |
| XAPQ(2,5,4,30) | | |

MODEP1

Name: MODEP1

Function: print blade modes

| | | |
|----------------|--|--------|
| TYPE | | R1DATA |
| HINGE | | |
| NCOLB | | |
| NONROT | | |
| NCOLT | | |
| RCPL | | |
| EFLAP | | |
| ELAG | | |
| KFLAP | | |
| KLAG | | |
| RCPLS | | |
| TSPRNG | | |
| RADIUS | | |
| OMEGA | | RTR1CM |
| NBM | | |
| NIM | | |
| NGM | | |
| NUGC | | |
| NUGS | | |
| KTO | | |
| KTC | | |
| KTR | | |
| IB | | |
| MB | | INC1CM |
| SB | | |
| IO | | |
| IP(5) | | |
| T75OLD | | MD1CM |
| NU(20) | | |
| NUNR(20) | | |
| ETA(2,10,11) | bending modes at $r = (j-1).1, j = 1 \text{ to } 11$ | |
| ETAP(2,10,11) | | |
| ETAPP(2,10,11) | | |
| WT(11) | | |
| WTO | | |
| WTC | | |
| WTR | | |
| ZETA(5,11) | torsion modes at $r = (j-1).1, j = 1 \text{ to } 11$ | |
| ZETAP(5,11) | | |
| ETAPH(2,10) | | |
| KPB(10) | | |
| KPG | | |

MODEP1

MD1CM

DEL1
DEL2
DEL3
DEL4
DEL5

BODYC

Name: BODYC

Function: initialize airframe parameters at trim

Wind tunnel trim case: section 4.1.3

\vec{r} , R_{SF} with Θ_T/Ψ_T rotations: sections 4.1.3, 4.1.5

Free flight trim case: section 4.1.1

Calculate R_e : section 4.2.1

Calculate $R_e^T I^* R_e$, $-M^*(\vec{V} \times) R_e$, G , $(\vec{V} \times) R_e \vec{k}_F$: section 4.2.4

Airframe gust velocity in body axes: section 4.1.4

THETFT

PHIFT

PSIFP

THETFP

THETAT

PSIT

CONTCM

DEBUG

VEL

OPTRIM

TMDATA

MSTAR

MSTARG

BODYCM

ISTAR(3,3)

RSF10(3,3)

RSF20(3,3)

RHUB10(3)

RHUB20(3)

RWBO(3)

RHTO(3)

RVTO(3)

ROFFO(3)

RSF1(3,3)

RSF2(3,3)

RHUB1(3)

RHUB2(3)

RWB(3)

RHT(3)

RVT(3)

ROFF(3)

VXREKF(3)

MXRE(3,3)

GMTRX(3,3)

IBODY(3,3)

REULER(3,3)

RFV(3,3)

RFE(3,3)
KE(3)
VELF(3)
VCLIMB
VSIZE

VGWBV(3)
VGHTV(3)
VGVTV(3)
VGWBF(3)
VGHTF(3)
VGVTf(3)

BODYC

BODYCM

GUSTCM

ENGNC

Name: ENGNC

Function: initialize drive train parameters at trim

Engine damping: section 4.3.1

Drive system inertia: section 5.3

Drive system spring, damping, mass matrices: section 5.1.9

Drive system static elastic matrix: section 5.1.10

Calculate C_p : section 5.1.5

Calculate C_D : section 5.1.9

| | | |
|----------|-------------------------|--------|
| DEBUG | | TMDATA |
| OPENGNC | | |
| OPRTR2 | | TRIMCM |
| NBLD1 | | R1DATA |
| NBLD2 | | R2DATA |
| IB1 | | RTR1CM |
| OMEGA1 | | |
| GAMMA1 | | |
| CD1(2) | | |
| CPSI1(2) | | |
| IB2 | | RTR2CM |
| OMEGA2 | | |
| GAMMA2 | | |
| CD2(2) | | |
| CPSI2(2) | | |
| I01 | | INC1CM |
| QT1 | | |
| QDZ1 | | |
| I02 | | INC2CM |
| QT2 | | |
| QDZ2 | | |
| CQS1 | $-\delta 2C_Q/\sigma a$ | QR1CM |
| CQS2 | $-\delta 2C_Q/\sigma a$ | |
| KIGOVE | | ENDATA |
| KIGOV1 | | |
| KIGOV2 | | |
| GSE | | |
| GSI | | |
| KEDAMP | | |

ENGNC

ENGNCM

QTHRTL
IENG
IMI1
KMI2
KMR
MKE1
KME2
KPGOVE
KPGOV1
KPGOV2
T1GOVE
T1GOV1
T1GOV2
T2GOVE
T2GOV1
T2GOV2
QEDAMP
IRSTAR
MENG(6,6)
SENG(6,6)
DENG(6,6)
HENG0(2,2)

MOTNC1

Name: MOTNC1

Function: initialize rotor parameters at trim

Calculate α_{HP} , ψ_{HP} , M_{at} : sections 2.4.2, 4.1.2

Calculate R_G : section 4.1.4

Rotor gust velocity in shaft axes: section 4.1.4

Calculate c , \bar{c} : section 4.2.2

Calculate c^T : section 4.2.5

Calculate μ_x , μ_y , μ_z : section 4.1.2

DEBUG
MPSI

TMDATA

NSCALE
ISCALE
FSCALE
LSCALE

TRIMCM

IB
OMEGA
MTIP
MUX
MUY
MUZ
ALFHP
PSIHP
MAT

RTR1CM

RGUST(3,3)
CHUB(6,16)
CBHUB(3,3)
CHUBT(16,6)

ROTATE
NBLADE
RADIUS
MRA

R1DATA

NEM

BDDATA

DVBODY(6)

CONTCM

VGUSTV(3,30,36) gust at rotor disk, velocity axes
VGUSTS(3,30,36) gust at rotor disk, shaft axes
VGUSTH(3) gust at rotor hub, velocity axes

GUSTCM

MOTNC1

BODYCM

VELF(3)
RFV(3,3)
REULER(3,3)
RSF(3,3)
RHUB(3)
AMODE(6,10)

BODYM1

Name: BODYM1

Function: calculate airframe transfer function matrix

General reference: section 5.1.8

| | | |
|----------------|--|--------|
| DEBUG | | TMDATA |
| DOF(16) | airframe degrees of freedom | |
| MHARMF | | |
| FSCALE | | TRIMCM |
| NBLADE | | R1DATA |
| OMEGA | | RTR1CM |
| DPSI21 | $\Delta\psi_{21}$ (rad); 0. for rotor #1 | |
| CHUBT(16,6) | | |
| AMASS(10) | | BODYCM |
| ADAMPS(10) | | |
| ASPRNG(10) | | |
| ADAMPA(10) | | |
| IBODY(3,3) | | |
| MVXRE(3,3) | | |
| GMTRX(3,3) | | |
| MSTAR | | |
| NAM | | |
| HBODY(16,6,10) | | RH1CM |

ENGNM1

Name: ENGNM1

Function: calculate drive train transfer function matrix

General reference: section 5.1.9

| | | |
|------------|--|--------|
| DEBUG | | TMDATA |
| MHARMF | | |
| DOF(6) | drive train degrees of freedom | |
| FSCALE | | TRIMCM |
| NBLADE | | R1DATA |
| OMEGA | | RTR1CM |
| DPSI21 | $\Delta\psi_{z1}$ (rad); 0. for rotor #1 | |
| CD(2) | | |
| MENG(6,6) | | ENGNCM |
| SENG(6,6) | | |
| DENG(6,6) | | |
| NDM | | |
| HENG(6,10) | | RH1CM |

WAKEU1

Name: WAKEU1

Function: calculate uniform wake-induced velocity

General reference: section 2.4.3

Lagged thrust and moment: section 5.1.12

Vectors for aerodynamic interference: section 4.2.6

Interference induced velocity: section 4.2.6

| | |
|------------|--------|
| DEBUG | TMDATA |
| OPGRND | |
| HAGL | |
| MPSI | |
| DPSI | TRIMCM |
| COSPSI(36) | |
| SINPSI(36) | |
| LSCALE | |
| FSCALE | |
| MRA | R1DATA |
| RADIUS | |
| ROTATE | |
| FACTOR | |
| KHLMDA | |
| KFLMDA | |
| FXLMDA | |
| FYLMDA | |
| FMLMDA | |
| KINTH | |
| KINTF | |
| KINTWB | |
| KINTHT | |
| KINTVT | |
| INFLOW(6) | |
| RA(30) | RTR1CM |
| OMEGA | |
| MUX | |
| MUY | |
| MUZ | |
| MRAO | R2DATA |
| RADUSO | |
| OMEGAO | RTR2CM |
| RSF(3,3) | BODYCM |
| RHUB(3) | |
| RWB(3) | |
| RHT(3) | |
| RVT(3) | |
| KE(3) | |

| | |
|-----|-----------|
| CT | C_T |
| CMY | C_{M_y} |
| CMX | C_{M_x} |

CTOLD
 CMXOLD
 CMYOLD
 VIND(3,30,36)
 LAMBDA
 FGE
 COSE
 ZAGL
 VINT(3,30,36)
 LAMBDI
 LAMBDW(3)
 LAMBDH(3)
 LAMBDV(3)
 LAMBD(3)
 EINTW(3)
 EINTH(3)
 EINTV(3)

WAKEU1

QR1CM

WKV1CM

WAKEN1

Name: WAKEN1(LEVEL)

Function: calculate non-uniform wake induced velocity

General reference: section 3.1.4

Calculate R_{TF} : section 3.1.3

$$R_{TF} = R_{TS} R_{SF}$$

$$R_{21} = (R_{SF})_{\text{other rotor}} R_{TF}^T$$

Lagged circulation: section 5.1.12

Interpolate induced velocity: linear interpolation between inflow points, constant beyond first or last point

Calculate mean induced velocity: TPP normal component, area-weighted mean

| | | |
|-----------|---|--------|
| LEVEL | rotor wake level: 0 for uniform inflow (only replace old circulation) | |
| DEBUG | | TMDATA |
| MPSI | | |
| DPSI | | TRIMCM |
| MRA | | R1DATA |
| ROTATE | | |
| INFLOW(6) | | |
| RA(30) | | RTR1CM |
| DRA(30) | | |
| DP21M | $\Delta\psi_{z1}$ (rad); 0. for rotor #1 | |
| DPSI21 | $\Delta\psi_{z1}$ (rad); $-\Delta\psi_{z1}$ for rotor #2 | |
| MRAO | other rotor | R2DATA |
| ROTATO | | |
| RAO(30) | | RTR2CM |
| DRAO(30) | | |
| NG(30) | | W2DATA |
| MRG | | |
| NL(30) | | |
| MRL | | |
| FACTOR | | |
| OPVXVY | | |
| KNW | | |
| OPRTS | | |
| NLO(30) | other rotor | W2DATA |
| MRLO | | |
| RSF(3,3) | | BODYCM |
| RSFO(3,3) | other rotor | |

GAM(30,36)
CRC(36)
BETAC
BETAS

BETACO
BETASO

other rotor

GAMOLD(30,36)
CRCOLD(36)
VIND(3,30,36)
LAMBDA
VINT(3,30,36)
VORH(3,36)
LAMBDI
VWB(3,36)
VHT(3,36)
VVT(3,36)
VOFF(3,36)
LAMBOW(3)
LAMBOW(3)
LAMBOW(3)
LAMBOW(3)

MR
ML
MI
MW
MH
MV
MO
C(3,20000)
CNW(3,20000)

WAKEN1

QR1CM

QR2CM

WKV1CM

WKC1CM

INRTM1

Name: INRTM1

Function: calculate rotor transfer function matrix

General reference: section 5.1.6

Aerodynamic spring and damping: section 2.2.20

| | | |
|----------------|--|--------|
| DEBUG | | TMDATA |
| DOF(15) | rotor bending and torsion degrees of freedom | |
| DOFT(4) | | |
| MPSI | | |
| MHARM | | |
| RA(30) | | RTR1CM |
| DRA(30) | | |
| CMEAN | | |
| MUZ | | |
| NUGC | | |
| NUGS | | |
| CGC | | |
| CGS | | |
| GLAG | | |
| CTO | | |
| CTC | | |
| CTR | | |
| NBM | | |
| NTM | | |
| NGM | | |
| NBMT | | |
| GAMA | γ | |
| KEPSI(21,36) | | TRIMCM |
| HRTR(16,16,21) | | RH1CM |
| CT | C_T | QR1CM |
| LAMBDA | | WKV1CM |
| BETA(21,10) | | MNR1CM |
| THETA(21,5) | | |
| BETAG(21) | | |
| FORCE(16,36) | | AEF1CM |
| NBLADE | | R1DATA |
| GSB(10) | | |
| GST(5) | | |
| MRA | | |
| CHORD(30) | | |
| SIGMA | | |
| XA(30) | | |
| XAC(30) | | |

INTRM1

MD1CM

NU(20)
ETAPH(2,10)
KPG
KPB(10)
AETA(2,10,3) bending modes at r_i , $i = 1$ to MRA
AZETA(5,30) torsion modes at r_i , $i = 1$ to MRA
WT(11)
WTO
WTC
WTR
MB
:
:
XAPQ(2,5,4,30)
MQDQ(10,10)
:
:
MPP(5,5)
IQDQS(10,10)
:
:
SPQS(5,10)

INC1CM

INRTI

Name: INRTI(MX,H,KEEP,LMINV,MMINV)

Function: calculate inverse of transfer function matrix

| | |
|-------------|--|
| MX | dimension of H_n |
| H(MX*MX) | complex matrix H_n to be inverted |
| KEEP(MK) | integer vector designating degrees of freedom to be retained; 0 for unused degrees of freedom |
| LMINV(MX+1) | scratch vector |
| MMINV(MX+1) | scratch vector |

MOTNH1

Name: MOTNH1

Function: calculate harmonics of hub motion

General reference: sections 5.1.5, 5.1.11

| | | |
|-------------|--------------------------------------|----------------------|
| DEBUG | | TMDATA |
| MHARM | | |
| MHARMF | | |
| GRAV | | TRIMCM |
| FSCALE | | |
| LSCALE | | |
| RADIUS | | R1DATA |
| ROTATE | | |
| NBLADE | | |
| OPHVIB(3) | | |
| OMEGA | | RTR1CM |
| CHUB(6,16) | | |
| CBHUB(3,3) | | |
| CPSI(2) | | |
| DPSI21 | $\Delta\psi_1$ (rad); 0. for rotor#1 | |
| KMASTC(10) | | BODYCM |
| KMASTS(10) | | |
| RSF(3,3) | | |
| KE(3) | | |
| NAM | | |
| NDM | | ENGNCM |
| DVBODY(6) | | CONTCM |
| DOMEGA | | |
| QSSTAT(10) | | MNSCM |
| PISTAT | | |
| PHI(10,16) | | MNR1CM |
| PSID(10,2) | (ψ_s, ψ_z) | |
| THTG(10) | $(\Delta\theta_{g1})$ | |
| PHIO(10,16) | | |
| PSIDO(10,2) | (ψ_s, ψ_z) | (due to other rotor) |
| THTGO(10) | $(\Delta\theta_{g1})$ | MNR2CM |
| ALF(10,6) | | |
| ... | | MNH1CM |
| DPSISO | | |

Name: MOTNR1(JSTART)

General reference: sections 5.1.6, 5.1.13

Lag damper moment: section 2.2.16

Calculate coning and tip-path plane tilt: section 3.1.3

Calculate hub reactions: section 5.1.7

JSTART azimuth index j_{start}

```

MPSI
MPSIR
DEBUG
MHARM
MHARMF
DOFT(4)

```

```

NBLADE                                R1DATA
GAMMA                                RTR1CM

```

NBM

NTM

NGM

NBM'

GLAG

MLD

DZLD

CGC

CGS

NUGS

NUGC

KPB(10) MD1CM

KPG

ETAPH(2,10)

```
ETATIP(2,10)      bending mode at r = 1
```

BO

BC

BS

BETA(21,10) MNR1CM

THETA(21,5)

BETAG(21)

DPSI

COSPSI(36)

SINPSI(36)

KEPSI(21,36)

HRTR(16,16,21) RH1CM

| | | |
|----------------|-------------------|--------|
| | | MOTNR1 |
| FORCE(16,36) | | AEF1CM |
| FHUB(6,36) | | |
| TORQUE(36) | | |
| SAVE(36,20) | | |
| Q(10) | | AEMNCM |
| : | | |
| : | | |
| DTT | | |
| MB | | INC1CM |
| SB | | |
| IO | | |
| IQ(10) | | |
| SQ(2,10) | | |
| IQA(2,10) | | |
| IQO(10) | | |
| IFXO | | |
| IMXO | | |
| IP(5) | | |
| IPP(5,5) | | |
| IPO(5) | | |
| XAPQ(2,5,4,30) | | |
| MQDQ(10,10) | | |
| : | | |
| : | | |
| MPP(5,5) | | |
| IQDQ(10,10) | summed over q_j | |
| : | | |
| : | | |
| SPQ(5,10) | | |

MOTNB1

Name: MOTNB1(PSI)

Function: calculate blade and hub motion

General reference: section 5.1.5

Rigid pitch p_r : section 5.1.3

| | | |
|-------------|--------|--------|
| PSI | ψ | |
| Q(10) | | AEMNCM |
| : | | |
| DTT | | |
| MHARM | | TMDATA |
| MHARFM | | |
| NBLADE | | R1DATA |
| NBM | | RTR1CM |
| NTM | | |
| NGM | | |
| KPB(10) | | MD1CM |
| KPG | | |
| T75 | | CONTCM |
| T1C | | |
| T1S | | |
| BETA(21,10) | | MNR1CM |
| THETA(21,5) | | |
| BETAG(21) | | |
| ALF(10,6) | | MNH1CM |
| : | | |
| DPSISO | | |

AEROF1

Name: AEROF1(JPSI,QT,MQ,MP,CMX,CMZ,CFX,CFZ,CFR)

Function: calculate blade aerodynamic forces

Calculate $XAP = \vec{X}_{Ak}$: section 2.2.19

Section velocity components: section 2.4.2

Calculate U, M, ϕ, α : section 2.4.1

ϕ in rad, α in deg

Calculate $\dot{\alpha}c/V$: section 2.4.7

Calculate $\cos \Lambda$: section 2.4.6

REVFLW = 1 if just crossed reverse flow boundary

Tip loss correction: section 2.4.5

Section forces and pitch moment: section 2.4.1

$$FZ = F_z/ac_m, FX = F_x/ac_m, FR = F_r/ac_m, MA = M_a/ac_m$$

Circulation: section 2.4.9

Unsteady lift, moment, and circulation: sections 2.4.8, 2.4.9

$$LUS = L_{us}/ac, MUS = M_{us}/ac, GUS = \Gamma_{us}/ac$$

Maximum circulation outboard r_{Gmax} : section 3.1.4

JPSI azimuth index j

QT(4) q_{jtrim}

MQ(10) M_{Qkaero}/ac

MP(5) M_{Pkaero}/ac

CMX $C_{m_x}/\sigma a$

CMZ $C_{m_z}/\sigma a$

CFX $C_{f_x}/\sigma a$

CFZ $C_{f_z}/\sigma a$

CFR $C_{f_r}/\sigma a$

Q(10)

DQ(10)

DDQ(10)

P(5)

DP(5)

DDP(5)

BG

DBG

DDBG

AHUB(6)

DAHUB(6)

DDAHUB(6)

AEMNCM

| | | |
|----------------|--|--------|
| PS | | AEROF1 |
| DPS | | AEMNCM |
| DDPS | | |
| DEBUG | | TMDATA |
| MPSI | | |
| DPSI | | TRIMCM |
| FSCALE | | |
| COSPSI(36) | | |
| SINPSI(36) | | |
| MRA | | R1DATA |
| CHORD(30) | | |
| TWIST(30) | | |
| THETZL(30) | | |
| XA(30) | | |
| XAC(30) | | |
| RGMAX | | |
| RFA | | |
| XFA | | |
| OPUSLD | | |
| RA(30) | | RTR1CM |
| DRA(30) | | |
| MTIP | | |
| OMEGA | | |
| CMEAN | | |
| FTIP(30) | | |
| MUX | | |
| MUY | | |
| MUZ | | |
| NBM | | |
| NTM | | |
| NBMT | | |
| RGUST(3,3) | | |
| CHUB(6,16) | | |
| XAPQ(2,4,5,30) | | INC1CM |
| T75 | | CONTCM |
| DVBODY(6) | | |
| VIND(3,30,36) | | WKV1CM |
| VINT(3,30,36) | interference velocity from other rotor | WKV2CM |
| GAM(30,36) | | QR1CM |
| CIRC(36) | | |
| SAVE(30,36,19) | | AES1CM |
| VGUST(3,30,36) | gust at rotor disk, shaft axes | GUSTCM |
| VGUSTH(3) | gust at rotor hub, velocity axes | |

AEROF1

MD1CM

ETA(2,10,30) bending modes at r_i , $i = 1$ to MRA
ETAP(2,10,30)
ETAPP(2,10,20)
ZETA(5,30) torsion modes at r_i , $i = 1$ to MRA
ZETAP(5,30)
DEL1
DEL2
DEL3
DEL4
DEL5

AEROS1

Name: AEROS1(ALPHA,DALPHA,COSYAW,MACH,JPSI,IR,REVFLW,CL,CD,CM,CDR,OPTION)

Function: calculate blade section aerodynamic coefficients

Corrected Mach number: section 2.4.5

Stall model, delayed α : section 2.4.7

Yawed flow, effective α : section 2.4.6

Calculate 2-D airfoil characteristics at effective α and M: section 2.4.7

Section characteristics corrected for yawed flow and stall delay:
sections 2.4.6, 2.4.7

Dynamic stall vortex loads: section 2.4.7

| | |
|--------|---|
| ALPHA | angle of attack α (deg) |
| DALPHA | $\dot{\alpha}_c/V$ |
| COSYAW | $\cos \Lambda$ |
| MACH | Mach number M |
| JPSI | azimuth index j |
| IR | radial station index i |
| REVFLW | integer parameter: 1 if just crossed reverse flow boundary |
| CL | c_x |
| CD | c_d |
| CM | c_m |
| CDR | $c_{d\text{radial}}$ |
| OPTION | integer parameter: 0 for derivatives of coefficients in flutter analysis (no dynamic stall vortex loads, and calculated data not saved) |

STATE(30,36,3)

AES1CM

DCLMAX(30,36)

DCDMAX(30,36)

DCMMAX(30,36)

MEFF(30,36,3)

AEFF(30,36,3)

DCLDS(30,36)

DCDDS(30,36)

DCMDS(30,36)

MRA

R1DATA

MCORRL(30)

MCORRD(30)

MCORRM(30)

AEROS1

R1DATA

TAUL
TAUD
TAUM
ADELAY
AMAXNS
PSIDS(3)
ALFDS(3)
ALFRE(3)
CLDSP
CDDSP
CMDSP
OPYAW
OPSTLL
OPCOMP

DEBUG
MPSI

TMDATA

AEROT1

Name: AEROT1(ALPHA,MACH,RADIAL,OPTION,CL,CD,CM)

Function: interpolate airfoil tables

General reference: section 2.4.4

| | |
|--------|---|
| ALPHA | angle of attack α (deg) |
| MACH | Mach number M |
| RADIAL | radial station r/R |
| OPTION | integer parameter: if 1 calculate c_l , if 2 calculate c_d , if 3 calculate c_m , if 4 calculate all three coefficients |
| CL | c_{l2D} |
| CD | c_{d2D} |
| CM | c_{m2D} |

NAB
NA(20)
A(20)
NMB
NM(20)
M(20)
NRB
R(11)
CLT(5000)
CDT(5000)
CMT(5000)

A1TABL

BODYV1

Name: BODYV1

Function: calculate harmonics of airframe motion

General reference: section 5.1.8

DEBUG

TMDATA

MPSI

MHARMF

NBLADE

R1DATA

NAM

BODYCM

HBODY(16,6,10)

RH1CM

FHUB(6,36)

AEF1CM

PHI(10,16)

MNR1CM

KEPSI(21,36)

TRIMCM

ENGNV1

Name: ENGNV1

Function: calculate harmonics of drive train motion

General reference: section 5.1.9

| | |
|--------------|--------|
| DEBUG | TMDATA |
| MHARMF | |
| MPSI | |
| NBLADE | R1DATA |
| NDM | ENGNCM |
| TORQUE(36) | AEF1CM |
| PSID(10,6) | MNR1CM |
| HENG(6,10) | RH1CM |
| KEPSI(21,36) | TRIMCM |

MOTNF1

Name: MOTNF1

Function: calculate rotor generalized forces

General reference: section 5.1.7

C_I/σ and C_X/σ for trim: section 5.2.1

DEBUG

MPSI

SIGMA

GAMMA

MUX

MUY

MUZ

CHUBT(16,6)

FHUB(6,36)

FHUBM(6)

QRTR(6)

CLS

CXS

CTS

CYS

CPS

CT

CMX

CMY

TMDATA

R1DATA

RTR1CM

AEF1CM

QR1CM

MOTNS

Name: MOTNS

Function: calculate static elastic motion

General reference: section 5.1.10

| | | |
|--------------|--------------------------------|--------|
| DEBUG | | TMDATA |
| DOFA(16) | airframe degrees of freedom | |
| DOFD(6) | drive train degrees of freedom | |
| OPRTR2 | | TRIMCM |
| CHUBT1(16,6) | | RTR1CM |
| CHUBT2(16,6) | | RTR2CM |
| DDALF1(6) | | MNH1CM |
| DDALF2(6) | | MNH2CM |
| FHUBM1(6) | | QR1CM |
| FHUBM2(6) | | QR2CM |
| ASPRNG(10) | | BODYCM |
| ACNTL(4,10) | | |
| NAM | | |
| HENGO(2,2) | | ENGNCM |
| NDM | | |
| DELF | | CONTCM |
| DELE | | |
| DELA | | |
| DELR | | |
| MB1 | | INC1CM |
| MB2 | | INC2CM |
| QSSTAT(10) | | MNSCM |
| PISTAT | | |
| PESTAT | | |

BODYF

Name: BODYF(LEVEL1,LEVEL2)

Function: calculate airframe generalized forces

General reference: section 4.2.6

| | | |
|-------------|--|--------|
| LEVEL1 | wake level for rotor #1 and rotor #2: 0 for | |
| LEVEL2 | uniform inflow | |
| DEBUG | | TMDATA |
| MPSI | | |
| AFLAP | | |
| GAMMA | reference rotor | TRIMCM |
| SIGMA | | |
| RADIUS | | |
| OMEGA | | |
| OPRTR2 | | |
| VBODY(3) | $(\dot{x}_F \ \dot{y}_F \ \dot{z}_F)$ | CONTCM |
| WBODY(3) | $(\dot{\phi}_F \ \dot{\theta}_F \ \dot{\psi}_F)$ | |
| DELF | | |
| DELE | | |
| DELA | | |
| DELR | | |
| DDZF | | |
| CANTHT | | BDDATA |
| CANTVT | | |
| REULER(3,3) | | BODYCM |
| RWB(3) | | |
| RHT(3) | | |
| RVT(3) | | |
| VELF(3) | | |
| QWB(6) | | QBDCM |
| QHT(6) | | |
| QVT(6) | | |
| SAVE(31) | | |
| VIW1(3,36) | | WKV1CM |
| VIH1(3,36) | | |
| VIV1(3,36) | | |
| LMDAW1(3) | | |
| LMDAH1(3) | | |
| LMDAV1(3) | | |

VIW2(3,36)
VIH2(3,36)
VIV2(3,36)
LMDAW2(3)
LMDAH2(3)
LMDAV2(3)

GWB(3)
GHT(3)
GVT(3)

gust in F axes

BODYF

WKV2CM

GUSTCM

BODYA

Name: BODYA(VWB,VHT,VVT,WWB,AFLAP,DELF,DELE,DELA,DELR,DAWB,
FWB,MWB,FHT,FVT,ANGLES)

Function: calculate body aerodynamic forces

General reference: section 4.2.6

| | |
|-----------|--|
| VWB(3) | velocity (u, v, w) at wing-body, horizontal tail, |
| VHT(3) | and vertical tail; F axes; ft/sec or m/sec |
| VVT(3) | |
| WWB(3) | angular velocity (p, q, r); rad/sec |
| AFLAP | flap angle δ_F (deg) |
| DELF | flaperon control δ_f (rad) |
| DELE | elevator control δ_e (rad) |
| DELA | aileron control δ_a (rad) |
| DELR | rudder control δ_r (rad) |
| DAWB | $\dot{\alpha}_{WB}$ (rad/sec) |
| FWB(3) | $(D/q, Y/q, L/q)_{WB}$; ft ² or m ² |
| MWB(3) | $(M_x/q, M_y/q, M_z/q)_{WB}$; ft ³ or m ³ |
| FHT(2) | $(D/q, L/q)_{HT}$; ft ² or m ² |
| FVT(2) | $(D/q, L/q)_{VT}$; ft ² or m ² |
| ANGLES(6) | $(\alpha_{WB}, \beta_{WB}, \alpha_{HT}, \alpha_{VT}, \epsilon, \varphi)$; deg |

CANTHT

BDDATA

CANTVT

BADATA

LFTAW

⋮

OPTINT

WAKEC1

Name: WAKEC1(LEVEL)

Function: calculate influence coefficients for nonuniform inflow

General reference: sections 3.1.3, 3.1.4

Calculate h for axisymmetric wake: section 3.1.6

Ground effect parameters: sections 2.4.3, 3.1.5

Calculate first blade/vortex intersection age and core bursting
age: section 3.1.7

Wake age loop:

$$LANDJ = (2 - 1) * MR * MPSI + j$$

$$JTEMJ = j_{te} - j$$

Burst/unburst core radius: section 3.1.7

Axisymmetric far wake: section 3.1.6

Complete C and C_{NW} for axisymmetric geometry: section 3.1.6

LEVEL wake analysis: 0 for uniform inflow, 1 for
 prescribed wake, 2 for free wake geometry

| | | |
|------------|--|--------|
| NBLADE | | R1DATA |
| RADIUS | | |
| ROTATE | | |
| RRCOT | | |
| CHORD(30) | | |
| MRA | | |
| INFLOW(6) | | |
| ROTATO | other rotor | R2DATA |
| RADUSO | | |
| OMEGA | | RTR1CM |
| CMEAN | | |
| RA(30) | | |
| PINTER(36) | | |
| PBURST(36) | | |
| DPSI21 | $\Delta\psi_{z_1}$ (rad); $-\Delta\psi_{z_1}$ for rotor #2 | |
| OMEGAO | other rotor | RTR2CM |
| BETAC | | QR1CM |
| BETAS | | |
| BETASO | | QR2CM |
| BETASO | | |
| MPSI | | TMDATA |
| DEBUG | | |
| DEBUGV | debug print control for VTXL and VTXS | |
| OPGRND | | |
| HAGL | | |

| | | |
|------------|-------------|--------|
| DPSI | | WAKEC1 |
| LSCALE | | TRIMCM |
| FSCALE | | |
| RWB(3) | | BODYCM |
| RHT(3) | | |
| RVT(3) | | |
| RHUB(3) | | |
| RHUBO(3) | other rotor | |
| ROFF(3) | | |
| RSF(3,3) | | |
| RSFO(3,3) | other rotor | |
| KE(3) | | |
| RFE(3,3) | | |
| K2T | | WG1CM |
| MUTPP(3) | | |
| KNW | | W1DATA |
| KRW | | |
| KFW | | |
| KDW | | |
| RRU | | |
| FRU | | |
| PRU | | |
| FNW | | |
| DVS | | |
| DLS | | |
| CORE(5) | | |
| OPCORE(2) | | |
| WKMODL(13) | | |
| OPNWS(2) | | |
| LHW | | |
| OPHW | | |
| OPRTS | | |
| VELB | | |
| DPHIB | | |
| DBV | | |
| QDEBUG | | |
| MRG | | |
| NG(30) | | |
| MRL | | |
| NL(30) | | |
| MRLO | other rotor | W2DATA |

WAKEC1

WKC1CM

MR

ML

MI

MW

MH

MV

MO

C(3,20000)

CNW(3,20000)

WAKEB1

Name: WAKEB1(PSI,OPTION,RBR,RBT,RB)

Function: calculate blade position

General reference: section 3.1.3

| | | |
|--------------|---|--------|
| PSI | Ψ (rad) | |
| OPTION | integer parameter controlling calculation of \vec{r}_b : if 1, at r_{ROOT} and 1; if 2, at circulation stations; if 3, at inflow stations | |
| RBR(3) | \vec{r}_b at r_{ROOT} | |
| RBT(3) | \vec{r}_b at tip ($r = 1$) | |
| RB(3,30) | \vec{r}_b at inflow or circulation stations | |
| MPSI | | TMDATA |
| MHARMF | | |
| MHARM | | |
| RFA | | R1DATA |
| ZFA | | |
| XFA | | |
| NBLADE | | |
| RROOT | | |
| NBM | | RTR1CM |
| RA(30) | | |
| OPWKBP(3) | | W1DATA |
| MRC | | |
| NG(30) | | |
| MRL | | |
| NL(30) | | |
| BETA(21,10) | | MNR1CM |
| BETAG(21) | | |
| PSIS(10) | | MNH1CM |
| PSISO | | |
| ETA(2,10,30) | bending modes at r_i , $i = 1$ to MRA | MD1CM |
| ETAR(2,10) | bending modes at r_{ROOT} | |
| ETAT(2,10) | bending modes at tip ($r = 1$) | |
| DEL1 | | |
| DEL2 | | |
| DEL3 | | |

VTXL

Name: VTXL(R1,R2,RP,MODEL,OPCORE,CORE,DLS,CHORD,PSI,OPGRND,ZAGL,RTE,
V1,V2,DEBUG)

Function: calculate vortex line segment induced velocity

General reference: section 3.1.7

Calculate: $S1 = s_1/s$, $S2 = s_2/s$, $RMSQ = r_m^2$

Lifting surface correction:

ANGLS = Λ (deg)

HLS = h (-1.0 for no correction)

RSINL = $r \sin \Lambda$, COSL = $\cos \Lambda$, SINL = $\sin \Lambda$

LLL = L_{11} , LLS = L_{1s} , FACTLS = L_{1s}/L_{11}

Image element in ground effect: section 3.1.5

| | |
|----------|---|
| R1(3) | \vec{r}_1 (at ϕ) |
| R2(3) | \vec{r}_2 (at $\phi + \Delta\psi$) |
| RP(3) | \vec{r}_P (at P) |
| MODEL | integer parameter: 1 for stepped vorticity distribution, 2 for linear vorticity distribution |
| OPCORE | integer parameter defining vortex core type: 0 for distributed, 1 for concentrated vorticity |
| CORE | vortex core radius r_c |
| DLS | d_{1s} for lifting surface correction, LT 0. to suppress |
| PSI | Ψ ; required for $d_{1s} \geq 0$ only |
| CHORD | chord c at P; required for $d_{1s} \geq 0$ only |
| OPGRND | integer parameter: 0 for out of ground effect |
| ZAGL | z_{AGL} ; required in ground effect only |
| RTE(3,3) | R_{TE} ; required in ground effect only |
| DEBUG | integer parameter: debug print if GE 3 |
| V1(3) | $\Delta \vec{v}$ due to Γ_1 (at ϕ) |
| V2(3) | $\Delta \vec{v}$ due to Γ_2 (at $\phi + \Delta\psi$) |

VTXS

Name: VTXS(R1,R2,R3,R4,RP,MODEL,MODELS,OPCORE,CORET,CORES,DVS,
OPGRND,ZAGL,RTE,MDLT,MDLS,VT1,VT2,VS1,VS3,DEBUG)

Function: calculate vortex sheet segment induced velocity

General reference: section 3.1.8

Image element in ground effect: section 3.1.5

| | |
|----------|--|
| R1(3) | \vec{r}_1 |
| R2(3) | \vec{r}_2 |
| R3(3) | \vec{r}_3 |
| R4(3) | \vec{r}_4 |
| RP(3) | \vec{r}_p |
| MODEL | integer parameters defining trailed and shed vorticity |
| MODELS | model: 0 to omit, 1 for stepped line, 2 for linear line, 3 for sheet |
| OPCORE | integer parameter defining vortex core type: 0 for distributed, 1 for concentrated vorticity |
| CORET | r_c for trailed vorticity (LT 0. for s/2) |
| CORES | r_c for shed vorticity (LT 0. for t/2) |
| DVS | d_{vs} for sheet edge test; LT 0. to suppress |
| OPGRND | integer parameter: 0 for out of ground effect |
| ZAGL | z_{AGL} ; required in ground effect only |
| RTE(3,3) | R_{TE} ; required in ground effect only |
| DEBUG | integer parameter: debug print if GE 3 |
| MDLT | integer parameters specifying trailed and shed vorticity |
| MDLS | model used |
| VT1(3) | $\Delta \vec{v}_t$ due to Γ_1 (at ϕ , outside edge) |
| VT2(3) | $\Delta \vec{v}_t$ due to Γ_2 (at $\phi + \Delta \Psi$, outside edge) |
| VS1(3) | $\Delta \vec{v}_s$ due to Γ_1 (at ϕ , outside edge) |
| VS3(3) | $\Delta \vec{v}_s$ due to Γ_3 (at ϕ , inside edge) |

$$(\Delta v_{t3} = -\Delta v_{t1}, \Delta v_{t4} = -\Delta v_{t2})$$

$$(\Delta v_{s2} = -\Delta v_{s1}, \Delta v_{s4} = -\Delta v_{s3})$$

GEOME1

Name: GEOME1(K,L,LEVEL,RWT,RWSO,RWSI)

Function: evaluate wake geometry

General reference: section 3.1.3

K $k (\phi = k \Delta \psi)$
L $\lambda (\psi = \lambda \Delta \psi)$
LEVEL wake analysis: 1 for prescribed wake geometry, 2 for
 free wake geometry
RWT(3) \vec{r}_w at tip vortex
RWSO(3) \vec{r}_w at sheet inside edge
RWSI(3) \vec{r}_w at sheet outside edge

| | |
|--------------|--------|
| MPSI | TMDATA |
| DPSI | TRIMCM |
| KRWG | W1DATA |
| KFWG | G1DATA |
| RBR(3,36) | |
| RBT(3,36) | WG1CM |
| MUTPP(3) | |
| DZT(144) | |
| DRT(144) | |
| K2T | |
| DZSI(144) | |
| DRSI(144) | |
| K2SI | |
| DZSO(144) | |
| DRSO(144) | |
| K2SO | |
| DFWG(3,2304) | |

Name: GEOMR1(LEVEL)

General reference: section 3.1.3

LEVEL wake analysis: 1 for prescribed wake geometry, 2 for
 free wake geometry

TM DATA

TRIMCM

R1 DATA

 Θ_{tw} at r_i , $i = 1$ to MRA

MRA

WKV1CM

WKV 2CM

W1DATA

QR1CM

 C_T

RTR1CM

WG1CM

K 250

GEOMF1

Name: GEOMF1

Function: calculate free wake geometry distortion

General reference: section 3.2

Subprograms required: WGAM, DCALC, NWCAL, WQCAL, VSCAL, QSVL, QCVL, QVS

| | | |
|--------------|---|--------|
| DEBUG | integer parameter controlling debug print: GE 1, print D at $\phi = 2\pi/N$ each iteration; GE 2, allow printing; GE 3, controlled by IPWGDB and QWGDB | TMDATA |
| MPSI | (maximum 24, multiple NBLADE) | |
| SIGMA | | R1DATA |
| NBLADE | | |
| PHIBWG(36) | core burst age $\phi_b(\Psi)$ (rad) | RTR1CM |
| DBV | | W1DATA |
| MUTPP(3) | | WG1CM |
| DFWG(3,2304) | | |
| LAMBDA | | WKV1CM |
| FACTGE | | |
| LAMBDI | interference velocity, due to other rotor | WKV2CM |
| CONING | β_o (rad) | QR1CM |
| CIRC(36) | $\Gamma/\Omega^2 R$ | |
| KFWG | | G1DATA |
| OPFWG | | |
| ITERWG | | |
| FACTWG | | |
| WGMODL(2) | | |
| RTWG(2) | | |
| COREWG(4) | | |
| MRVBWG | | |
| LDMWG | | |
| NDMWG(36) | | |
| IPWGDB(2) | | |
| QWGDB | | |
| DQWG(2) | | |
| DEL1 | | MD1CM |
| DEL2 | | |

MINV

Name: MINV(A,N,D,L,M)

Function: calculate inverse of matrix

Input:

A(N*N) matrix (destroyed)

N dimension

L(N+1) scratch vector

M(N+1) scratch vector

Output:

A(N*N) A - inverse

D determinant of A; 0. if A is singular

MINVC

Name: MINVC(A,N,D,L,M)

Function: calculate inverse of complex matrix

Input:

A(N*N) complex matrix

N dimension

L(N+1) scratch vector

M(N+1) scratch vector

Output:

A(N*N) complex A - inverse

D complex determinant of A; 0. if A is singular

EIGENJ

Name: EIGENJ(N,NM,A,T,EVR,EVI,VECR,VECI,INDIC,NEI)

Function: calculate eigenvalues and eigenvectors of matrix

Subprograms required: SCALEM, HESQR, REALVE, COMPVE

Input:

| | |
|--------|---|
| A(N*N) | matrix A (destroyed) |
| N | order of matrix |
| NM | actual first dimension of arrays; maximum 100 |
| NEI | 0 to calculate only eigenvalues |
| T | dummy argument (set to 24. in EIGENJ) |

Output:

| | |
|-----------|--|
| EVR(N) | real part of eigenvalues of A |
| EVI(N) | imaginary part of eigenvalues of A |
| VECR(N*N) | real part of eigenvectors of A |
| VECI(N*N) | imaginary part of eigenvectors of A |
| INDIC(N) | if 2, no error; if 1, eigenvector not found; if 0, neither eigenvector nor eigenvalue found |

DERED

Name: DERED(NX,NV,DOF,CON,A2,A1,A0,B,DOF1,DOF0,NAMEX,NAMEV)

Function: eliminate equations and variables from system of differential equations

Input:

| | |
|-------------------------------------|--|
| NX | dimension of matrices |
| NV | dimension of matrices |
| DOF(NX) | integer vector designating degrees of freedom to be eliminated: DOF = 0 if variable not used |
| CON(NV) | integer vector designating controls to be eliminated: CON = 0 if variable not used |
| A2(NX*NX) A1(NX*NX) A0(NX*NX) | coefficient matrices |
| B(NX*NV) | control matrix |
| DOF0(NX) | integer vector |
| DOF1(NX) | integer vector |
| NAMEX(NX) | vector of variable names |
| NAMEV(NV) | vector of control names |

Output:

| | |
|-------|------------------------------------|
| A2 | reconstructed matrices and vectors |
| A1 | |
| A0 | |
| B | |
| DOF0 | |
| DOF1 | |
| NAMEX | |
| NAMEV | |

QSTRAN

Name: QSTRAN(MX,MX0,MX1,MV,A2,A1,A0,B0,DOF1,DOF0,NAMEX)

Function: quasistatic reduction of system of linear differential equations

General reference: section 6.3.2

Input:

| | |
|-----------|--|
| A2(MX*MX) | coefficient matrices |
| A1(MX*MX) | |
| A0(MX*MX) | |
| B0(MX*MV) | control matrix |
| DOF1(MX) | integer vector designating first order degrees of freedom: $DOF1(I) = 0$ for x_i first order |
| DOF0(MX) | integer vector designating quasistatic variables: $DOF0(I) = 0$ for x_i quasistatic |
| MX | number of degrees of freedom, maximum 60 |
| MX0 | number of quasistatic degrees of freedom |
| MX1 | number of first order degrees of freedom |
| MV | number of controls, maximum 60 |
| NAMEX(MX) | vector of variables names |

Output:

| | |
|-------|--|
| A2 | reconstructed matrices and vectors |
| A1 | |
| A0 | |
| B0 | |
| DOF1 | |
| NAMEX | |
| MX | number of remaining degrees of freedom (MX-MX0) |
| MX1 | number of remaining first order degrees of freedom |

CSYSAN

Name: CSYSAN(N,MX,MX1,MV,A2,A1,A0,B0,NFREQ,FREQ,NSTEP,DOF1,FSCALE,
NAMEX,NAMEV,NFOUT)

Function: analyze system of constant coefficient linear differential equations

General reference: sections 7.2, 7.2.1

| N | calculation control |
|--------------|-----------------------------------|
| | N = 0 1 2 10 11 12 |
| eigenvalues | x x x x x x |
| eigenvectors | x x x x |
| check sums | x x |
| zeros | x x x |

A2(MX*MX) coefficient matrices
A1(MX*MX)
A0(MX*MX)
B0(MX*MV) control matrix
MX number of degrees of freedom
MX1 number of first order degrees of freedom
MV number of controls
 (maximum MX2 = 2*MX - MX1 = 60; maximum MV = 60)
DOF1(MX) integer vector designating first order degrees of
 freedom (zero columns in A0); DOF1(I) = 0 for x_1
 first order
FSCALE frequency scale factor ω (in rad/sec to obtain
 frequencies in Hz and times in sec); there is no
 print of dimensional eigenvalues if FSCALE \leq 0.
NAMEX(MX) vector of variables names
NAMEV(MV) vector of control names
NSTEP static response calculated if NSTEP \neq 0
NFREQ number of frequencies for which frequency response
 calculated; none if NFREQ \leq 0
FREQ(NFREQ) vector of frequencies (dimensionless) for calculation
 of frequency response
NFOUT unit number for printed output

CSYSAN

Output:

LAMDA(MX2)

eigenvalues

MX2

number of eigenvalues

available in following common block:

COMMON /EIGVC/LAMDA(60),MX2

COMPLEX LAMDA

DETRAN

Name: DETRAN(A,MX,MX1,MV,A2,A1,A0,B0,DOF1,NAMEX,NAME,NFOUT)

Function: transform equations to state variable form

General reference: section 7.1

Input:

| | |
|-----------|--|
| A2(MX*MX) | coefficient matrices |
| A1(MX*MX) | |
| A0(MX*MX) | |
| B0(MX*MV) | control matrix |
| MX | number of degrees of freedom, maximum 60 |
| MX1 | number of first order degrees of freedom |
| MV | number of controls, maximum 60 |
| DOF1(MX) | integer vector designating first order degrees of freedom; DOF1(I) = 0 for x_i first order |
| NAMEX(MX) | vector of variable names |
| NFOUT | unit number for printed output |

Output:

| | |
|------------|--------------------------|
| A(MX2*MX2) | coefficient matrix |
| B0(MX*MV) | control matrix |
| NAME(MX2) | vector of variable names |
| | (MX2 = 2 * MX - MX1) |

SINE

Name: SINE(W,A,ASQ,B0,MX,MX1,MV,NAME,NAMEV,NFOUT)

Function: calculate frequency response from matrices

General reference 7.2.3

Response calculation: for last MX states only

| | |
|--------------|---|
| W | frequency (dimensionless) |
| A(MX2*MX2) | coefficient matrix A |
| ASQ(MX2*MX2) | coefficient matrix squared, A^2 |
| B0(MX*MV) | control matrix |
| MX | number of degrees of freedom |
| MX1 | number of first order degrees of freedom |
| MV | number of controls (maximum MX2 = $2*MX - MX1 = 60$; maximum MV = 60) |
| NAME(MX2) | vector of variable names |
| NAMEV(MV) | vector of control names |
| NFOUT | unit number for printed output |

STATIC

Name: `STATIC(A,B0,MX,MX1,MV,NAME,NAMEV,NFOUT)`

Function: calculate static response from matrices

General reference: section 7.2.2

Response calculation: for last MX states only

| | |
|-------------------------|--|
| <code>A(MX2*MX2)</code> | coefficient matrix |
| <code>B0(MX*MV)</code> | control matrix |
| <code>MX</code> | number of degrees of freedom |
| <code>MX1</code> | number of first order degrees of freedom |
| <code>MV</code> | number of controls (maximum $MX2 = 2*MX - MX1 = 60$; maximum $MV = 60$) |
| <code>NAME(MX2)</code> | vector of variable names |
| <code>NAMEV(MV)</code> | vector of control names |
| <code>NFOUT</code> | unit number for printed output |

ZERO

Name: ZERO(A,B0,MX2,MX,MV,NX,NV)

Function: calculate zeros

General reference: section 7.2.4

| | |
|------------|---|
| A(MX2*MX2) | coefficient matrix |
| B0(MX*MV) | control matrix |
| MX2 | number of states, maximum 60 |
| MX | number of degrees of freedom |
| MV | number of controls |
| NX | state number i for which zeros to be calculated |
| NV | control number j for which zeros to be calculated |

Output:

| | |
|------------|--|
| LAMDAZ(MZ) | zeros of x_i/v_j |
| K1 | factor K_1 : $x_i/v_j = K_1 \frac{\pi(z-s)}{\pi(p-s)}$ |
| MZ | number of zeros |

available in the following common block:

```
COMMON /EIGVZ/LAMDAZ(60),K1,MZ
COMPLEX LAMDAZ
REAL K1
```

ZETRAN

Name: ZETRAN(Z,MZ)

Function: transform matrix for zero calculation

General reference: section 7.2.4

Input:

Z(MZ*MZ) matrix A^* (A with x_1 column replaced by v_j column of B)
MZ number of states, MX2

Output:

Z(MZ*MZ) matrix A_1 (eigenvalues of which are the zeros);
 the factor K_1 is in $Z(MZ*MZ+1)$
MZ number of zeros
 GT 0 finite number of zeros exists
 EQ 0 no zeros, $K_1 = Z(1)$
 LT 0 x_1 not controllable by v_j

BODE

Name: BODE(MX,MX1,MV,A2,A1,A0,B0,DOF1,NAMEX,NAMEV,NPLOT,NAMEXP,NAMEVP,
NX,NV,NFO,NF1,ND,MSCALE,NFOUT)

Function: calculate and printer-plot transfer function (Bode plot)

General reference: section 7.2.3

| | |
|------------|--|
| A2(MX*MX) | coefficient matrices |
| A1(MX*MX) | |
| A0(MX*MX) | |
| B0(MX*MV) | control matrix |
| MX | number of degrees of freedom |
| MX1 | number of first order degrees of freedom |
| MV | number of controls |
| | (maximum MX2 = 2*MX - MX1 = 60; maximum MV = 60) |
| DOF1(MX) | integer vector designating first order degrees of freedom; DOF1(I) = 0 for x_1 first order |
| NAMEX(MX) | vector of variable names |
| NAMEV(MV) | vector of control names |
| NPLOT | frequency response calculation method: if 1, from matrices; if 2, from poles and zeros |
| NAMEXP(NX) | vector of variable names to be plotted (inconsistent names ignored) |
| NAMEVP(NV) | vector of control names to be plotted (inconsistent names ignored) |
| NX | number of degrees of freedom to be plotted; maximum 30 |
| NV | number of controls to be plotted; maximum 30 |
| NFO | exponent (base 10) of beginning frequency |
| NF1 | exponent (base 10) of end frequency |
| ND | frequency steps per decade |
| | (maximum NF = (NF1 - NFO)*ND + 1 = 151) |
| MSCALE | magnitude plot scale: if 1, plot relative maximum value; if 2, plot relative 10**K; if 3 plot relative 10. |
| NFOUT | unit number for printed output |

BODEPP

Name: BODEPP(HM,HP,NF0,NF1,ND,OPTION,NFOUT)

Function: printer-plot transfer function magnitude and phase

| | |
|--------|---|
| HM(N) | transfer function magnitude |
| HP(N) | transfer function phase (degrees, -180 to 180) ($N = (NF1 - NF0) * ND + 1$) |
| NF0 | exponent (base 10) of beginning frequency |
| NF1 | exponent (base 10) of end frequency |
| ND | frequency steps per decade |
| OPTION | magnitude plot scale: if 1, plot relative maximum value; if 2, plot relative 10^{**K} ; if 3, plot relative 10. |
| NFOUT | unit number for printed output |

TRACKS

Name: TRACKS(A2,A1,A0,B0,MX,MX1,MV,DOF1,OMEGA,NAMEX,NAMEV,NPLOT,
PERICD,DELT,TMAX,NAMEXP,NAMEVP,NX,NV,NFOUT)

Function: calculate and printer-plot time history of time-invariant
system response

General reference: section 7.2.5

Calculate eigenvalue matrix and modal matrix:

MRED = M without unused states (rows)

MB = $M^{-1}B$ without unused controls (columns)

| | |
|-----------|---|
| A2(MX*MX) | coefficient matrices |
| A1(MX*MX) | |
| A0(MX*MX) | |
| B0(MV*MX) | control matrix |
| MX | number of degrees of freedom |
| MX1 | number of first order degrees of freedom |
| MV | number of controls |
| | (maximum MX2 = 2*MX - MX1 = 60; maximum MV = 60) |
| DOF1(MX) | integer vector designating first order degrees of freedom; DOF1(I) = 0 for x_i first order |
| NAMEX(MX) | vector of variable names |
| NAMEV(MV) | vector of control names |
| OMEGA | frequency scale (rad/sec) |
| NPLOT | control input type |
| | 1 step |
| | 2 impulse |
| | 3 cosine impulse |
| | 4 sine doublet |
| | 5 square impulse |
| | 6 square doublet |
| PERIOD | period T (sec) for impulse or doublet (NPLOT = 3 to 6) |
| DELT | time step (sec) |
| TMAX | maximum time (sec) |
| | (maximum NX*NV*TMAX/DELT = 7200) |

TRACKS

| | |
|------------|---|
| NAMEXP(NX) | vector of variable names to be plotted (inconsistent names ignored) |
| NAMEVP(NV) | vector of control names to be plotted (inconsistent names ignored) |
| NX | number of degrees of freedom to be plotted; maximum 30 |
| NV | number of controls to be plotted; maximum 30 |
| NFCUT | unit number for printed output |

TRCKPP

Name: TRCKPP(TRACE,NX,NV,MT,DELT,NAMEXP,NAMEVP,NFOUT)

Function: printer-plot time history

TRACE(NX,NV,MT) array of time history traces to be plotted
NX number of degrees of freedom to be plotted
NV number of controls to be plotted
(maximum $NX \cdot NV = 26$)
MT number of time steps to be plotted
DELT time step (sec)
NAMEXP(NX) vector of variable names
NAMEVP(NV) vector of control names
NFOUT unit number for printed output

GUSTS

Name: GUSTS(A2,A1,A0,B0,MX,MX1,MV,MG,DOF1,NAMEX,RADIUS,OMEGA,GRAV,
EULER,VEL,LGUST,MGUST,NAMEXR,NAMEXL,ML,NAMEXA,MACC,
FREQA,RACC,NEM,ZETA,NAMEXB,NFCUT)

Function: calculate and print rms gust response

General reference: section 7.2.6

| | |
|-----------|---|
| A2(MX*MX) | coefficient matrices |
| A1(MX*MX) | |
| A0(MX*MX) | |
| B0(MX*MV) | control matrix (gust in last MG columns) |
| MX | number of degrees of freedom |
| MX1 | number of first order degrees of freedom |
| MV | number of controls and gusts |
| MG | number of gust components (maximum MX2 = 2*MX - MX1 + MACC + MG = 60) (maximum MG = 3) |
| DOF1(MX) | integer vector designating first order degrees of freedom; DOF1(I) = 0 for x_i first order |
| NAMEX(MX) | vector of variable names |
| RADIUS | length scale R (ft or m) |
| OMEGA | frequency scale Ω (rad/sec) |
| GRAV | acceleration due to gravity (ft/sec ² or m/sec ²) |
| EULER(2) | trim Euler angles θ_{FT} and ϕ_{FT} (rad); required for body axis acceleration only |
| VEL(3) | velocity components in body axis frame (divided by ΩR); only magnitude required (for τ_G) unless body axis acceleration calculated |
| LGUST(MG) | real vector of gust correlation lengths: if GT 0, dimensional correlation length L ($\tau_G = L/2V$); if EQ 0, L = 400. used; if LT 0, magnitude is correlation time τ_G (dimensionless), so break frequency is $\omega = \Omega/\tau_G$ |
| MGUST(MG) | real vector of gust component relative magnitudes |
| NAMEXR(3) | names of β_{1c} , ζ_{1c} , θ_{1c} in state vector (NAMEX); analysis assumes that β_{1s} , ζ_{1s} , θ_{1s} follow immediately (inconsistent names ignored) |

NAMEXL(ML) names of linear degrees of freedom in state vector (NAMEX) for dimensional output (ft or m, obtained from R); degrees of freedom not identified are angular (degrees) (inconsistent names ignored)

ML number of linear degrees of freedom

NAMEXA(MACC) names of degrees of freedom (NAMEX) for which acceleration calculated; last three names must equal ACCB to calculate body axis acceleration (all three or none) (inconsistent names ignored)

FREQA(MACC) accelerometer break frequency (Hz), in same order as NAMEXA; 2/rev used if FREQA ≤ 0 .

MACC number of accelerometers; none if MACC ≤ 0

RACC(3) x, y, z location of point at which body axis acceleration calculated (dimensionless)

ZETA(3,NEM) airframe elast mode shapes, k = 1 to NEM; required for body axis acceleration only

NEM number of airframe elastic modes; none if NEM ≤ 0 ; maximum 10

NAMEXB(6+NEM) names of ϕ_F , Θ_F , Ψ_F , x_F , y_F , z_F , q_{F1} ... q_{FNEM} in state vector (NAMEX); assumes all elastic airframe states are consecutive; required for body axis acceleration only (inconsistent names ignored)

NFOUT unit number for printed output

PSYSAN

Name: PSYSAN(MX,MX1,A2,A1,A0,PHI,DT,NT,MT,PERIOD,DOF1,NINT,NFOUT)

Function: analyze system of periodic coefficient linear differential equations

General reference: section 7.3

A2(MX*MX) coefficient matrices
A1(MX*MX)
A0(MX*MX)
MX number of degrees of freedom
MX1 number of first order degrees of freedom
 (maximum MX2 = 2*MX - MX1 = 60)
DOF1(MX) integer vector designating first order degrees
 of freedom (zero columns in A0); DOF1(I) = 0
 for x_i first order
DT time increment; may vary with NT, but for Runge-Kutta
 integration successive pairs must be equal
NT time step counter (NT = 0, 1, 2, ... MT)
MT total number of time steps in numerical integration;
 for Runge-Kutta integration, must be even
PERIOD period T of the system
PHI temporary storage of state transition matrix Φ and
 last A; dimension 2*MX2*MX2 for modified trapezoidal
 integration; dimension 3*MX2*MX2 for Runge-Kutta
 integration (MX2 = 2*MX - MX1)
NINT numerical integration method: if 1, modified
 trapezoidal method, error order DT**3; if 2,
 Runge-Kutta method, error order (2*DT)**5
NFOUT unit number for printed output

Output:

LAMDA(MX2) roots λ (principal value)

LAMDAC(MX2) eigenvalues λ_c of $\Phi(T)$

MX2 number of poles

 available in the following common block:

COMMON /EIGVP/LAMDA(60),LAMDAC(60),MX2
COMPLEX LAMDA,LAMDAC

PSYSAN

Typical usage:

```
DT = PERIOD/MT
DO 1 NT = 0,MT
  T = DT * NT
  calculate coefficient matrices at time T
1 CALL PSYSAN
```

DEFRAN

Name: DEFRAN(A,MX,MX1,A2,A1,A0,DOF1,NFOUT)

Function: transform equations to state variable form

General reference: section 7.1

Input:

| | |
|--------------------|---|
| $A2(MX \times MX)$ | coefficient matrices |
| $A1(MX \times MX)$ | |
| $A0(MX \times MX)$ | |
| MX | number of degrees of freedom; maximum 60 |
| MX1 | number of first order degrees of freedom |
| DOF1(MX) | integer designator of first order degrees of freedom; DOF1(I) = 0 for x_1 first order |
| NFOUT | unit number for printed output |

Output:

| | |
|---------------------|--|
| $A(MX2 \times MX2)$ | coefficient matrix ($MX2 = 2 \times MX - MX1$) |
|---------------------|--|

MAINTB

Name: MAINTB

Function: airfoil table preparation

General reference: section 2.4.4

Subprograms required: AEROT, AEROPP, C81INT, C81RD, REDCL, TABFIX

AEROT

Name: AEROT(ALPHA,MACH,RADIAL,OPTION,CL,CD,CM)

Function: interpolate airfoil tables

General reference: section 2.4.4

| | |
|--------|---|
| ALPHA | angle of attack α (deg) |
| MACH | Mach number M |
| RADIAL | radial station r/R |
| OPTION | integer parameter: if 1 calculate c_x ; if 2 calculate c_d , if 3 calculate c_m , if 4 calculate all three coefficients |
| CL | c_{l2D} |
| CD | c_{d2D} |
| CM | c_{m2D} |

AEROPP

Name: AEROPP(CL,CD,CM,MA,AMAX)

Function: printer-plot airfoil aerodynamic characteristics

Calculate ordinate limits:

- a) c = maximum value of magnitude
- b) $N = \lceil \log c \rceil$ ($N = N - 1$ if $c < 1$.)
- c) $K = \lceil c/10^{**N} \rceil + 1$
- d) use for scale $X = K * 10^{**N}$

| | |
|--------|---|
| CL(MA) | array of c_l to be plotted |
| CD(MA) | array of c_d to be plotted |
| CM(MA) | array of c_m to be plotted |
| MA | number of angle of attack values; odd number |
| AMAX | maximum angle of attack; data in arrays for $\alpha = -\alpha_{\max}$ to α_{\max} , in MA steps |

3. COMPUTER SYSTEM SUBPROGRAMS

The following computer system subprograms (or the equivalent) are required to determine the calendar date and time of day, which form the identification for jobs and files.

a) CALL TIME(ETIME)

Function: returns time of day (8 alphanumeric characters) in array ETIME(2)

b) CALL DATE(IDATE)

Function: returns calendar date (8 alphanumeric characters) in array IDATE(2)

The following computer system subprograms (or the equivalent) are required in the timing subprogram.

a) CALL SETTIM(0,0)

Function: initializes timer

b) ETIME = INTVAL(0,0)

Function: returns CPU time, in milliseconds since initialization

4 CORE REQUIREMENTS

The program requires 4.04 megabytes of core storage. Of this total, 1.84 megabytes is for the subprograms and 2.20 megabytes is for the common blocks. The common blocks for the nonuniform inflow influence coefficients (both rotors) require 0.96 megabytes.

| | | | | | |
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